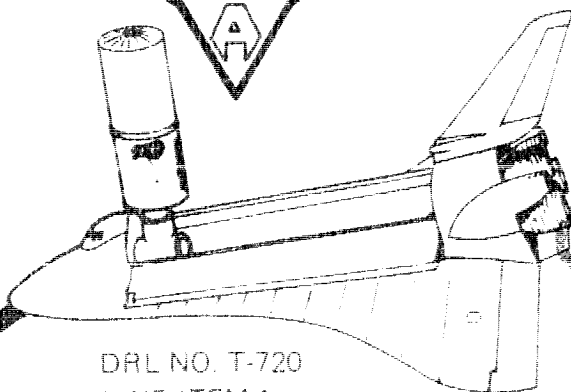
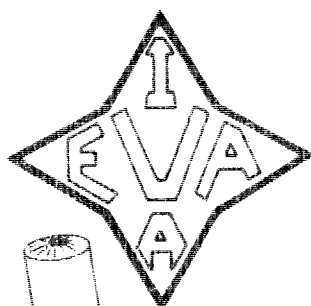


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**study of
space shuttle
eva/iva
support
requirements**

**VOLUME IV
REQUIREMENTS STUDY
FOR SPACE SHUTTLE
MOBILITY AIDS**

30 APRIL 1973



**VOUGHT
SYSTEMS DIVISION**

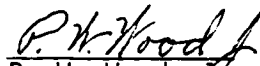
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EVA/IVA SUPPORT REQUIREMENTS

VOLUME IV
REQUIREMENTS STUDY FOR SPACE
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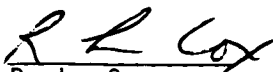
REPORT NO. T-192-RP05

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NASA-Johnson Spacecraft Center
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PREFACE

This document is submitted by the Vought Systems Division, LTV Aerospace Corporation, P.O. Box 5907, Dallas, Texas 75222, to the National Aeronautics and Space Administration, Johnson Spacecraft Center (JSC), Houston, Texas, in accordance with Contract No. NAS9-12507, dated 28 March 1972. It is the Final Requirements Study for Space Shuttle Mobility Aids Report, and fulfills part of the requirements of DRL No. T-720, Line Item 1, DRD MA-182-T. It contains final detailed documentation on Work Breakdown Structure Subtask 1.4 Mobility Aids. The following additional volumes complete the final documentation:

- Volume I - TECHNICAL SUMMARY REPORT
- Volume II - EVA/IVA TASKS, GUIDELINES, AND CONSTRAINTS DEFINITION
- Volume III - REQUIREMENTS STUDY FOR SPACE SHUTTLE PRESSURE SUITS
- Volume V - REQUIREMENTS STUDY FOR SPACE SHUTTLE EMERGENCY
IV SUPPORT

A special task on the 10 psia Orbiter Cabin Impacts, plus a delta-task on Emergency IV Requirements, were conducted for NASA subsequent to the completion of basic contract work. This was accomplished by agreement between the Technical Monitor, Mr. D. L. Boyston of NASA-JSC, and the VSD Project Engineer, Dr. R. L. Cox. In this connection, the detail of final documentation was relieved, and Volumes I, II, and V are largely updates of briefing material previously presented to NASA.

Work on this contract was conducted over the time period 20 March 1972 through 30 April 1973.

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INTRODUCTION AND SUMMARY

Mobility aids include; (1) translational devices to assist crewmen in moving from place to place and in moving equipment packages (cargo) from place to place; (2) restraint devices for crewmen at the worksite to prevent undesired induced motion between the crewman and the worksite while he performs tasks; and (3) other necessary worksite provisions. This report reviews existing devices in each of the categories and generates new concepts, as required. Analyses of the EVA/IVA task scenarios are then conducted and the various concepts are compared to task requirements to determine the best set of mobility aids. The recommended baseline set of mobility aids for the Shuttle orbiter is then defined and their requirements are specified.

The baseline set of mobility aids identified for the shuttle orbiter includes:

- . Manipulator work platform end effector
- . Handholds at planned worksites, as required
- . Portable handholds outside manipulator work platform end effector reach envelope
- . Permanent handrails around the periphery of the cargo bay, on the docking module, and on the exterior of the sortie lab
- . Emergency handrails on the manipulator arm
- . Mission-specific handrails as required
- . Permanent lighting in orbiter payload bay and illuminating permanent handrails and handholds
- . Mission-specific lighting for planned EVA/IVA
- . Portable lighting for unscheduled EVA/IVA

- . Skylab foot restraints
- . Waist safety tethers
- . Solid worksite equipment retention
- . Space suit pockets for small cargo

During the study it was found that electroadhesors are viable candidate portable handholds for electroconductive surfaces, and should be evaluated further for use on payloads and the Orbiter exterior. Burn-off handholds are viable for emergency use on the vehicle exterior, and should be studied further. Appendix A presents information on Apollo burn-off handholds.

The Manipulator Work Platform emerged as, perhaps, the most useful and viable tool for task accomplishment. Some detail study was carried out on this device, and a conceptual design is presented. The concept includes an open work platform which attaches to the manipulator arm, and folds for stowage in the cargo bay. Controls, restraints, anchoring devices, lighting, and tool/cargo stowage provisions are provided on the work platform end effector.

A free-flying maneuvering work platform was studied and is defined in some detail, should a requirement for this equipment evolve. Some potential for this item exists for servicing outside the contaminant cloud or orbiter exterior inspection/repair. No firm requirement has been identified at this time.

Much information has been obtained on EVA mobility aids requirements and other aspects of zero-g EVA during the Apollo transearth EVA's. Appendix B presents notes from an interview with Ken Mattingly, Apollo 16 Command Module Pilot, relative to his zero-g EVA experience.

1.0 MOBILITY AIDS DISCUSSION AND RECOMMENDATIONS

Mobility aids have been used on Gemini and Apollo missions, are to be used on Skylab, are to be tested on Skylab and the Shuttle, and are being tested in simulated space flight conditions on earth. In the following discussion those mobility aids used on actual missions, planned for Skylab and the Shuttle, and showing positive results in simulated space flight tests are included. The discussion includes descriptions of devices, how they are used, results obtained, and evaluations and recommendations relative to usage on the orbiter vehicle for EVA/IVA.

The mobility aids are divided into three groups: 1) translational devices to assist crewmen in moving from place to place and in moving equipment packages (cargo) from place to place; 2) restraint devices for crewmen at worksites to prevent unwanted induced motion between the crewmen and the worksite while performing tasks; and 3) other necessary worksite provisions.

1.1 Translational Devices

Crew transit over the exterior of the vehicles in the orbital extravehicular environment was accomplished on the Gemini and Apollo missions by the use of several types of fixed and portable handholds and handrails. Crew transfer between two undocked vehicles was demonstrated through free-floating techniques, self-propulsion and umbilical or tether pull-in. These methods were demonstrated within a maximum separation distance of 15 feet. Hand Held Maneuvering Units (HHMU) were evaluated briefly on the Gemini IV and X EVA missions as a free space personnel transportation device. An Astronaut Maneuvering Unit (AMU) was carried on one Gemini mission for evaluation of maneuvering in space independent of spacecraft systems. The evaluation was not conducted, but the capability did exist for free-flight translation over large distances.

Experiments in free-flight crew and cargo transfer are to be conducted on both the Skylab and Shuttle programs. The objectives of these experiments are to: (1) assess and develop man's ability to efficiently use the maneuvering systems in performing extravehicular activities; (2) develop the operational skills required for navigation, docking/anchoring, cargo transfer, resupply, astronaut rescue, space assembly, maintenance and repair, and (3) develop the hardware and procedures required to support future extravehicular manipulations (Ref. 4). The maneuvering units to be utilized in these experiments are listed below.

- o Astronaut Maneuvering Research Vehicle (AMRV) consisting of:
 - An Automatically Stabilized Maneuvering Unit (ASMU)
 - A Hand Held Maneuvering Unit (HHMU)
- o Foot Controlled Maneuvering Unit (FCMU)
- o Astronaut Maneuvering Unit (AMU)
- o Maneuverable Work Platform (MWP)

Orbital extravehicular cargo transfer on previous spaceflights has been limited to retrieval of small experiment samples. On 4 Gemini missions and on Apollo 9 these transfer tasks were accomplished by using vehicle mounted handholds and handrails, and equipment and crew tethers.

Apollo 15, 16, and 17 transearth crew and cargo transfer between the Command Module hatch and the Scientific Instrument Module (SIM) bay was accomplished using spacecraft mounted handholds and handrails. A wrist tether was used to restrain the cargo during manual hand-held transfer. The largest unit transferred weighed 85 earth pounds.

The Skylab program will require EVA to retrieve and replace film magazines. This extravehicular operation will require the EVA crewman to

translate approximately 30 feet along the spacecraft structure to reach the task worksites. Standard handrails and handholds will be provided along the transfer routes for crewman translation. Electrically powered extendible booms will be used as the primary method of transferring cargo from the worksites to the Airlock Module (AM). As a backup to the extendible boom system, a manually actuated "endless clothesline" device will be available. Under nominal Skylab EVA operation, six excursions will be made to the external worksites and approximately 1500 earth pounds of cargo transported (Ref.1).

1.1.1 Manual Translational Devices

1.1.1.1 Gemini EVA Equipment

Two handrails were installed to assist the pilot in moving from the cockpit to the adapter equipment section. The metal rectangular handrails were 0.55 by 1.25 inches in cross section. The forward handrail was 21 inches long and the aft handrail was 46 inches long. There was a 9-inch gap between the two sections. Both handrails were flush with the spacecraft surface at launch, but were 1.5 inches above the spacecraft surface when deployed. The aft handrail was deployed automatically, and the forward handrail was deployed manually.

The Gemini pilots used the handrails to traverse the 8 feet from the cockpit to the aft end of the spacecraft. Limited suit mobility and interference of the Extravehicular Life Support System (ELSS) chestpack required the pilots to move their hands one after the other in a sideways motion along the handrail, rather than hand-over-hand. Comments by the pilots indicated that this handrail was a satisfactory device for transit between two points on the spacecraft surface. A rectangular, rather than a cylindrical, cross section was preferred by the pilots because the

rectangular shape offered more resistance to rotation for a given hand force and allowed better control of body attitude. In a pressurized Gemini suit, the width of the rectangular handrail (1.25 inches) was a good size for gripping.

A pair of large, cylindrical, metal handbars was installed in the adapter equipment section to permit the pilot to move from the rectangular handrails to the work area and to provide restraint while positioning his feet in foot restraints or while working. The two handbars were located symmetrically on each side of the work station. The handbars were retracted at launch and were pyrotechnically deployed on command from the crew. The method of travel, when using the large cylindrical handbars, was also to the side. The pilots were able to introduce the significant body torques required to position their feet in the foot restraints with these cylindrical handbars. The 1.38-inch diameter of the cylindrical handbars was the most favorable size.

Small cylindrical handrails were mounted on the right and left sides of the Gemini XII Gemini Agena Target Vehicle. They were made of unpainted metal 0.317 inch in diameter, and the two segments were 10.5 and 31.5 inches in length. The handrails were small enough to be used as waist tether attach points and as handholds.

A telescoping handrail was installed to facilitate transit from the spacecraft hatch to the spacecraft nose on Gemini XII. In the stowed configuration, the handrail was 37 inches long and 1-3/8 inches in diameter and was constructed of anodized aluminum. The pilot unstowed and manually extended the four-section handrail to a maximum length of 99 inches. The pilot then installed the small end (0.625-inch diameter) of the handrail in a special receptacle in the docking cone and the large end on a mounting bolt located

in the spacecraft center beam between the hatches.

The pilot used this handrail for transit between the spacecraft hatch and the spacecraft nose and as a handhold for several changes in body attitude. The flexibility of the handrail was reported by the pilot to be undersirable. When the handrail flexed, the pilot had less control of his body position and attitude (Ref. 2).

1.1.1.2 Apollo Orbital EVA Equipment

Planned extravehicular operation on Apollo 9 (Figure 1) provided the opportunity to support the developmental objectives of handrail evaluation and body control during translation. The EVA timelines specified that the Lunar Module Pilot would egress the lunar module, transfer to the open hatch in the command module, and then return to the lunar module. The initial plan was abbreviated but the modified extravehicular plan accomplished all of the primary EVA evaluation objectives.

Thermal samples were easily retrieved from the Command Module using the restraint and handrail systems provided. Body control by means of the Gemini dutch shoes and the rectangular handrail (1.25 in. by .62 in.) was considered by the EVA crewman to be excellent. All translation and stability evaluations were performed satisfactorily with a minimum of effort.

Transearth EVA operations were performed on the Apollo 15, 16 and 17 missions. The primary purpose of the EVA mission was to retrieve a 24 inch panoramic camera cassette (19.3 inches in diameter by 6.2 inches wide and weighing 85 pounds) and a 3 inch mapping camera cassette (10.5 inches in diameter by 8.5 inches wide and weighing 27 pounds) from the Scientific Instrument Module (SIM) located on the Command Service Module (CSM). Three

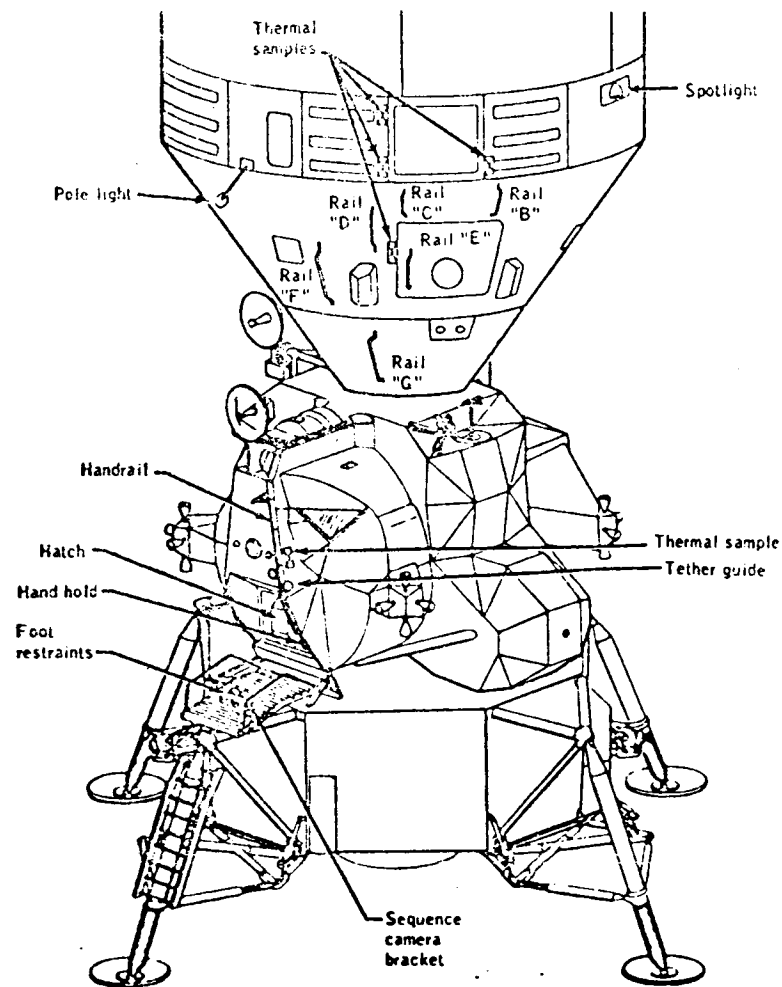


FIGURE 1. APOLLO 9 EVA RESTRAINT AND MOBILITY AID LOCATION (FROM REF. 1)

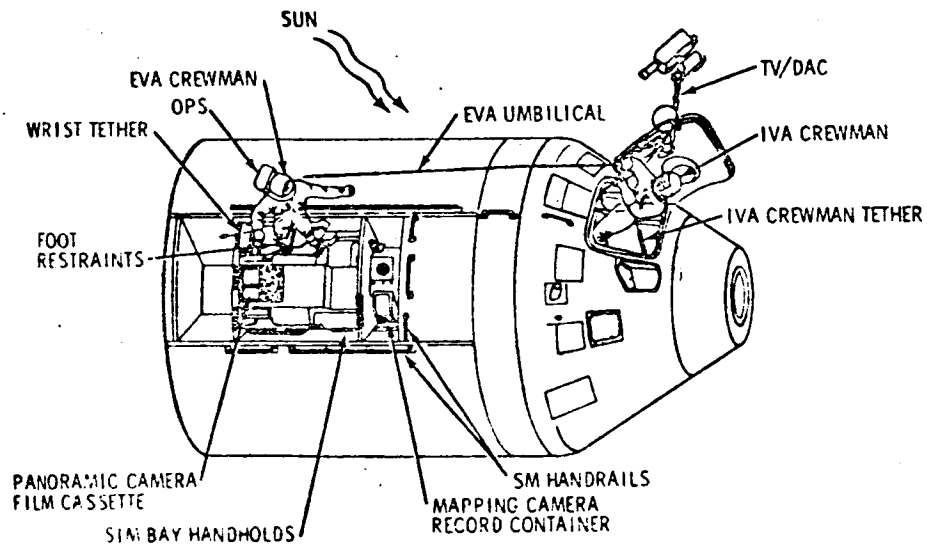


FIGURE 2. APOLLO 15 EVA FILM MAGAZINE RETRIEVAL (FROM REF. 1)

excursions were made to the SIM bay (Figure 2). Rectangular handrails and handholds were used to translate to and from the worksite. Each of the camera cassettes were attached to the EVA crewman by a wrist tether during translation.

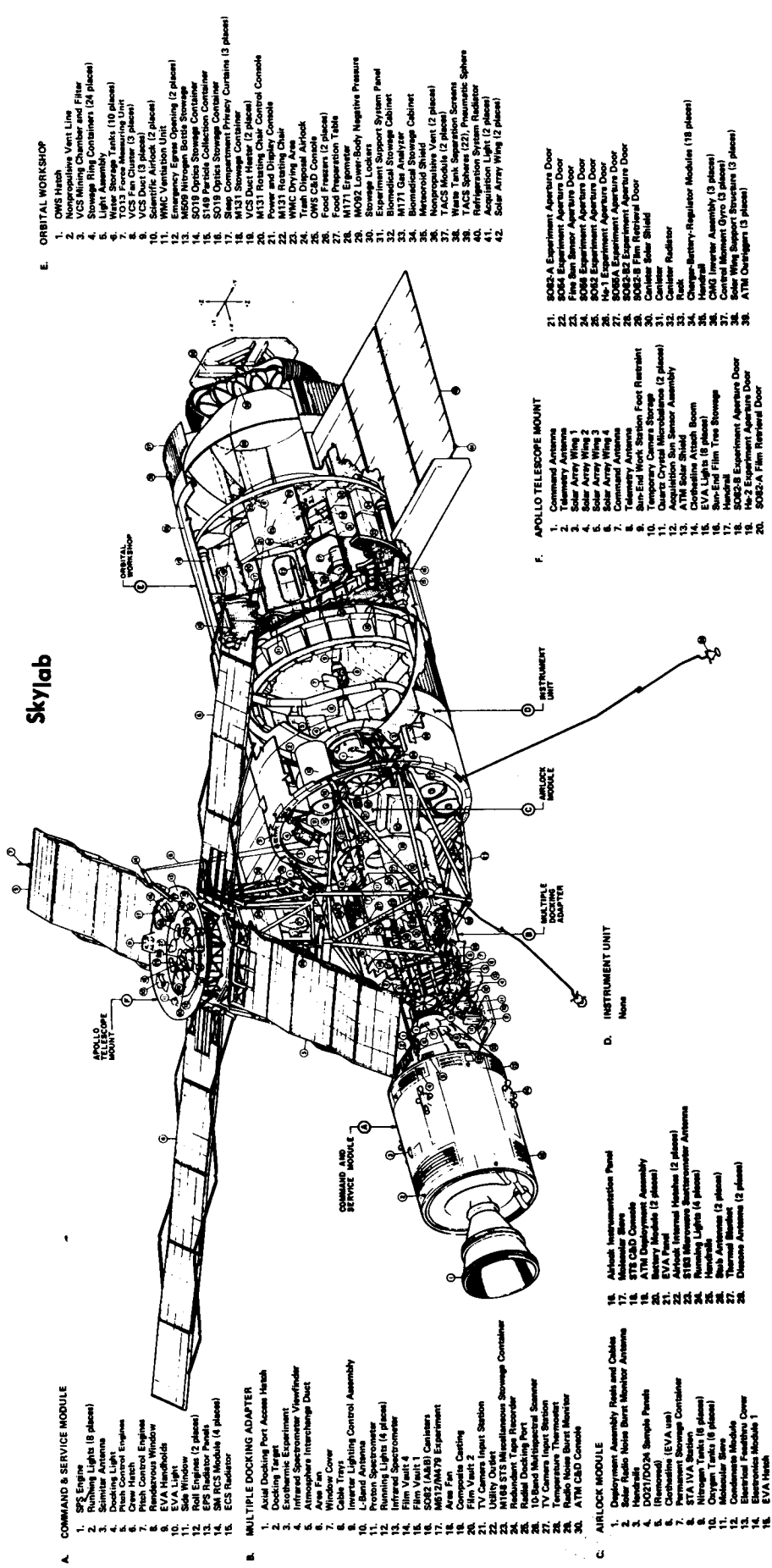
In addition to the camera film cassette retrieval activities, a microbial response experiment (M-191) was conducted on Apollo 16. This experiment required the EVA crewman to expose a self-contained Microbial Environment Exposure Device (MEED) to space radiation for a specified period of time near the end of the transearth EVA period.

No major problems were encountered during the Apollo 15, 16, and 17 transearth operations. Appendix B contains comments from the Apollo 16 EVA obtained during interview with Astronaut Ken Mattingly.

1.1.1.3 Skylab EVA Equipment

The Skylab cluster consists of a Saturn Workshop (SWS) with an Apollo Command Service Module (CSM) docked to it (Figure 3). The SWS is composed of an S-1VB Orbital Workshop (OWS), an Airlock Module (AM), a Multiple Docking Adapter (MDA), a Saturn V Instrument Unit (IU), and an Apollo Telescope Mount (ATM).

One primary objective of Skylab is the acquisition of photographic data on solar activity. This objective will be accomplished through the use of the ATM, which is a canister containing several telescopes and film magazines. The orbital EVA support for the ATM will consist of one astronaut translating between an Airlock Module (AM) and two workstations on the ATM, removing and replacing six film magazines, and returning the exposed film magazines to the AM. A second EVA astronaut will be stationed outside the AM to support the film retrieving astronaut, manage his umbilical, and



- A. COMMAND & SERVICE MODULE**
1. SPS Engine
 2. Running Lights (8 places)
 3. Running Antenna
 4. Docking Light
 5. Push Control Engines
 6. Push Control Engines
 7. Push Control Engines
 8. Rendezvous Window
 9. EVA Handholds
 10. EVA Light
 11. EVA Light
 12. Roll Engine (2 places)
 13. EPS Radiator Panels
 14. SM RCS Module (4 places)
 15. ECS Radiator
- B. MULTIPLE DOCKING ADAPTER**
1. Axial Docking Port Access Hatch
 2. Docking Target
 3. Exothermic Experiment
 4. Infrared Spectrometer Viewfinder
 5. Attenuation Interchange Duct
 6. Air Filter
 7. Window Cover
 8. Cable Trays
 9. Inverter Lighting Control Assembly
 10. L-Band Antenna
 11. Radio Frequency Interference Shield
 12. Running Lights (4 places)
 13. Infrared Spectrometer
 14. Film Vault 4
 15. Film Vault 1
 16. SPS Vent 1
 17. M812/M819 Experiment
 18. Composite Canister
 19. Film Vault 2
 20. TV Mount 2
 21. TV Mount 1
 22. M168 STS Miscellaneous Storage Container
 23. Radiant Time Recorder
 24. Radiant Time Recorder
 25. Radiant Time Recorder
 26. TV Camera Input Section
 27. Temperature Thermometer
 28. Radio Noise Burst Monitor
 29. ATM C&D Console
- C. AIRLOCK MODULE**
1. Deployment Assembly Rails and Cables
 2. Handholds
 3. Solar Radio Noise Burst Monitor Antenna
 4. D027/D028 Sample Panels
 5. Handholds
 6. Handholds (EVA use)
 7. Permanent Storage Container
 8. STA IVA Station
 9. Nitrogen Tanks (6 places)
 10. Oxygen Tanks (6 places)
 11. Oxygen Tanks
 12. Condensate Module
 13. Electrical Fan/Blower Cover
 14. EVA Hatch
- D. INSTRUMENT UNIT**
- None
- E. ORBITAL WORKSHOP**
1. OWS Hatch
 2. Nonpropulsive Vent Line
 3. VCS Mining Chamber and Filter
 4. Upper Ring Containers (24 places)
 5. Upper Ring Containers (24 places)
 6. Water Storage Tanks (10 places)
 7. TO33 Force Measuring Unit
 8. VCS Duct (3 places)
 9. VCS Duct (3 places)
 10. Scientific Airlock (2 places)
 11. WMC Ventilation Unit
 12. Emergency Egress Opening (2 places)
 13. S148 Periscope Storage Container
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 42. S148 Periscope Storage Container
- F. APOLLO TELESCOPE MOUNT**
1. Command Antenna
 2. Solar Array Wing 1
 3. Solar Array Wing 2
 4. Solar Array Wing 3
 5. Solar Array Wing 4
 6. Solar Array Wing 5
 7. Solar Array Wing 6
 8. Solar Array Wing 7
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 38. Solar Array Wing 37
 39. Solar Array Wing 38
 40. Solar Array Wing 39
 41. Solar Array Wing 40
 42. Solar Array Wing 41
- G. SKYLAB CLUSTER**
1. SPS Engine
 2. Running Lights (8 places)
 3. Running Antenna
 4. Docking Light
 5. Push Control Engines
 6. Push Control Engines
 7. Push Control Engines
 8. Rendezvous Window
 9. EVA Handholds
 10. EVA Light
 11. EVA Light
 12. Roll Engine (2 places)
 13. EPS Radiator Panels
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 40. Airlock Instrumentation Panel
 41. Airlock Instrumentation Panel
 42. Airlock Instrumentation Panel

FIGURE 3. The Skylab Cluster

assist him if necessary. A third crewman may be partially suited and working in the MDA, monitoring subsystems and serving as safety observer. Six separate EVA missions will be performed, each lasting approximately two and one-half hours.

During each of the six Skylab EVA missions, one of the EVA crewmen will be required to translate approximately 24 ft. from the AM hatch to the center workstation and about 30 ft. to the sun end workstation.

The manual translation devices consist of standard rectangular handrails and handholds for crewman translation and body positioning and several pieces of support hardware including film magazine clusters (Figure 4), tree receptacles, stowage containers, stowage hooks, endless clothesline, and equipment tethers, used to aid in the film magazine handling operations. The characteristics of the handholds and handrails on Skylab are shown in Table I.

The manually actuated "endless clothesline" device, called the ATM Contingency Transfer System (ACS) will be stowed on the side of the Film Transfer Booms (FTB). At each end are rings to snap into clothesline attach brackets at the work stations and a ring at each end to act as a sheave which the clothesline moves (Ref. 1).

1.1.1.4 Developmental Equipment

1.1.1.4.1 Handrails

Tests conducted in the water immersion simulator (WIS) at the Langley Research Center indicate that a crewman can perform cargo transfer tasks in zero-g using either a one or two rail mobility aid. (Ref. 3) The tests were conducted on packages ranging from 108 to 1640 earth pounds. The tests indicated that it was easier to move packages over about 300 pounds

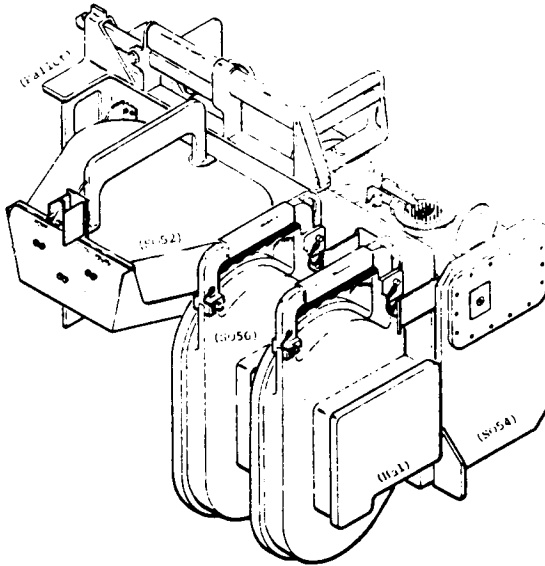


FIGURE 4. Skylab Film Transportation Tree with Associated Film Magazines (from Ref. 1)

TABLE I EVA HANDHOLD AND HANDRAIL CHARACTERISTICS

MOBILITY AIDS	CHARACTERISTICS					
	GRIP CROSS-SECTION	LOAD LIMITS (lbs.)	TYPE OF LOAD	DIRECTION OF LOAD	ALLOWABLE DEFLECTION (ins.)	REMARKS
HANDHOLDS	Rectangular 1.25 x .62 in with .25 in. corner radius	600	Concen- trated load	Any possible direction	0.5	<ul style="list-style-type: none"> o Standard Apollo type o Must provide 5.5 ins. of straight grasping surface
HANDRAILS	Rectangular 1.25 x .62 in with .25 in. corner radius	600	Concen- trated on most critical 2 ins. of member	Any possible direction	1.0	<ul style="list-style-type: none"> o Stand-off from space-craft surface should be 2.5 ins. minimum for glove clearance

(From Reference 1)

if two parallel rails were available.

The moment of inertia of the packages had more effect on the ease of handling than the weight. For packages having a moment of inertia less than approximately 15 slug-ft², handling was easy. Handholds were required on packages with a moment of inertia above approximately 15 slug-ft² when single handrails were used as mobility aids. No handholds were required on the packages if dual, parallel handrails were available, provided the size and shape of the package allowed two sides to be squeezed to obtain an adequate grip with both hands. The dual parallel handrails were gripped between the feet and legs leaving both hands for cargo handling.

1.1.1.4.2 Electroadhesive Devices

Studies and tests conducted by the Langely Research Center (Ref.9) and the Chrysler Corp. (Ref.20) indicate that electroadhesive devices can provide the desired adaptability for a wide range of tasks. These include the following classes of tasks; (1) astronaut and cargo transfer and maneuvering, (2) worksite restraint, (3) tool and equipment attachment, and others.

Tests conducted showed that electroadhesive force per unit area of up to 30 psi for vacuum environment and 6 psi for ambient pressures and temperatures could be obtained under laboratory conditions.

1.1.2 Powered Translational Devices

Powered translational devices are broken down into three categories for discussion: 1) Free-flying maneuvering Units; 2) Manipulators; and 3) Powered Cargo transfer devices.

1.1.2.1 Free-Flying Maneuvering Units

Maneuvering units which would allow crewmen to translate free in space have been studied, designed, and in some cases, tested in orbit

during the Gemini program. This experience has indicated that there are several functions to be considered in the selection of a maneuvering unit concept for a particular application. Table II lists these functions and gives candidates for providing these functions. The candidates shown are those considered to be viable in light of the past experience. The candidates can be combined to give a number of possible maneuvering unit concepts. Table III is a matrix showing all possible combinations with a concept identifier. Some concepts can be eliminated immediately because the candidates are not compatible, these are identified in the remarks column. Some concepts are identified as known devices which have been, or are to be, designed and tested. These are identified in the remarks column by the existing acronym.

1.1.2.1.1 Free-Flying Maneuvering Units Discussion

1.1.2.1.1.1 Concept 1

This concept can be considered in two forms: 1) a unit containing thrusters which are hand directed and hand fired (HHMU) or 2) a backpack unit with fixed thrusters fired by hand controllers. These two forms are discussed in the above order.

Several HHMU's were developed, tested, qualified and carried on the Gemini flights for evaluation (Fig.9). The units were designed for use in the general vicinity of the spacecraft. Although only limited evaluation of the units were performed on the Gemini program, the feasibility of the HHMU was established. The HHMU's provide the necessary force to propel and/or stop the crewman by expelling a high pressure gas medium through pusher and tractor type thrusters. The units are normally held in the right hand of the crewman and pointed in the desired direction of flight while maintaining the force vector through his center of gravity.

TABLE II FREE FLYING MANEUVERING UNIT
FUNCTIONS AND CANDIDATES

FUNCTIONS	CANDIDATE	REMARKS
Attitude Hold	A. None B. Automatic 1. Thrusters 2. CMG	
Attitude Change Sensing	A. Astronaut B. Rate Gyros	
Translation and Rotation	A. Propulsion 1. Compressed Gas 2. Monopropellant 3. Bipropellant B. Propulsion + CMG	
Control Means	A. Hands B. Feet	{ Hand held or hand controllers
Utilization Means	A. Strap On B. Work Platform	

TABLE III-FREE FLYING MANEUVERING UNITS

CONCEPT MATRIX

CONCEPT IDENTIFIER	FUNCTIONS AND CANDIDATES					REMARKS
	TRANSLATION AND ROTATION	ATTITUDE HOLD	ATTITUDE SENSING	CONTROL MEANS	UTILIZATION MEANS	
1	A. PROPELLSION 1. COMPRESSED GAS	A. NONE	A. ASTRONAUT	A. HANDS	A. STRAP ON	HMMU-GEMINI TAMRV-SKYLAR
2				B. FEET	B. WORK PLATFORM	ELIMINATE- NOTE 1.
3		B. AUTOMATIC 1. THRUSTERS	B. RATE GYROS		A. STRAP ON	FCMU-SKYLAR
4			A. ASTRONAUT	A. HANDS	B. WORK PLATFORM	ELIMINATE- NOTE 1/6.
5			B. RATE GYROS	B. FEET		ELIMINATE- NOTE 2.
6		B. AUTOMATIC 2. CMG	A. ASTRONAUT	A. HANDS	A. STRAP ON	ELIMINATE- NOTE 3.
7				B. FEET	B. WORK PLATFORM	AMRV-SKYLAR
8			B. RATE GYROS		A. STRAP ON	ELIMINATE- 1.1.312.4
				A. HANDS	B. WORK PLATFORM	ELIMINATE- NOTE 6.
				B. FEET	A. STRAP ON	ELIMINATE- 1.1.312.7
					B. WORK PLATFORM	ELIMINATE- NOTE 6.
						ELIMINATE- NOTE 7.
9	A. PROPELLSION 2. MONOPROPELLANT	A. NONE	A. ASTRONAUT	A. HANDS	A. STRAP ON	ANDRENE HMMU-GEMINI
10				B. FEET	B. WORK PLATFORM	ELIMINATE- NOTE 1.
			B. RATE GYROS		A. STRAP ON	ELIMINATE- NOTE 1/6.
			A. ASTRONAUT		B. WORK PLATFORM	ELIMINATE- NOTE 2.
11		B. AUTOMATIC 1. THRUSTERS	B. RATE GYROS	A. HANDS	A. STRAP ON	ELIMINATE- NOTE 3.
12				B. FEET	B. WORK PLATFORM	GEMINI AMU
13					A. STRAP ON	
				A. HANDS	B. WORK PLATFORM	ELIMINATE- NOTE 6.
14		B. AUTOMATIC 2. CMG	A. ASTRONAUT	A. HANDS	A. STRAP ON	
15				B. FEET	B. WORK PLATFORM	
16			B. RATE GYROS		A. STRAP ON	ELIMINATE- NOTE 6.
					B. WORK PLATFORM	ELIMINATE- NOTE 7.

TABLE III FREE FLYING MANEUVERING UNITS
CONCEPT MATRIX (CONTINUED)

CONCEPT IDENTIFIER	FUNCTIONS AND CANDIDATES					REMARKS
	TRANSLATION AND ROTATION	ATTITUDE HOLD	ATTITUDE CHANGE SENSING	CONTROL MEANS	UTILIZATION MEANS	
	B. PROPULSION + CMG	A. NONE B. AUTOMATIC 1. THRUSTERS B. AUTOMATIC 2. CMG	A. ASTRONAUT B. RATE GYROS	A. HANDS B. FEET		ELIMINATE - NOTE 4. ELIMINATE - NOTE 5.
17					A. STRAP ON B. WORK PLATFORM	AMRV-SKYLAB & AMU-SHUTTLE MWP-SHUTTLE
18					A. STRAP ON B. WORK PLATFORM	ELIMINATE - NOTE 6. ELIMINATE - NOTE 7.
19						

NOTES:

1. A WORK PLATFORM WITH NO ATTITUDE HOLD IS NOT A DESIRABLE CONCEPT.
2. THE RATE GYROS OUTPUT WOULD BE USELESS.
3. THE AUTOMATIC ATTITUDE HOLD HAS NO SENSOR
4. TRANSLATION AND ROTATION USING A CMG WILL HAVE ATTITUDE HOLD CAPABILITY, THEREFORE THIS COMBINATION WILL NOT EXIST.
5. TRANSLATION AND ROTATION USING A CMG WILL HAVE ATTITUDE HOLD CAPABILITY WITHOUT THRUSTERS, THEREFORE THIS COMBINATION WILL NOT EXIST.
6. CUSTOMARILY SPACECRAFT ARE HAND CONTROLLED SINCE MANEUVERING WORK PLATFORMS ARE SMALL SPACECRAFT, WHERE THE CREWMAN HAS HIS HANDS FREE, THE FOOT CONTROL MEANS WOULD BE UNDESIRABLE.
7. THE CONTROL MOMENT GYROS (CMG) ATTITUDE HOLD CANNOT UTILIZE A SEPARATE RATE GYRO ATTITUDE SENSOR INPUT.

The HHMU's are operated by squeezing a trigger mechanism that operates a throttle valve to provide gas flow to the tractor or pusher thrusters. The thrust is normally proportional to the displacement of the throttle valve trigger. A trigger preload force of 5 to 15 lbs. was common on the Gemini HHMU's. The Gemini IV and X units were evaluated on orbit. The characteristics of the Hand Held Maneuvering Units designed for use on the Gemini flights are shown in Table IV.

TABLE IV GEMINI HAND HELD MANEUVERING UNIT CHARACTERISTICS			
	Gemini IV	Gemini VIII	Gemini X
HHMU weight (lbs).	7.5	3*	3*
Weight of propellant (lbs)7	18	10.75
Propellant (gas)	Oxygen	Freon-14	Nitrogen
Thrust, tractor or pusher (lbs). . .	0 to 2	0 to 2	0 to 2
Specific impulse calculates(sec) . .	59	33.4	63
Total impulse (lbs-sec).	40	600*	677*
Total available velocity increment (ft/sec)	6	54	84
Trigger preload (lbs).	15	15	5
Trigger force at maximum thrust (lbs)	20	20	8
Storage tank pressure (psia)	4000	5000	5000
Regulated pressure (psia).	120	110+15	125+5
Nozzle area ratio.	50:1	5T:1	51:1

* The nitrogen propellant tank was mounted in the adapter section. The weight stated is for the HHMU only and does not include the weight of the umbilical, propellant tank and propellant.

The Gemini HHMU's ground based simulation indicated that confused tumbling motions might occur due to inertia coupling efforts, if excessive rotational velocities were reached. In view of this, rolling velocities were maintained close to zero and the crewman's mass distribution was kept as symmetrical as possible during the Gemini HHMU evaluations. The HHMU

evaluation scheduled for the Skylab program will include rotational maneuvers with some resulting translational cross coupling. The HHMU evaluations will be conducted as a part of the Astronaut Maneuvering Equipment experiment (M509) inside the Orbital Workshop (OWS) forward compartment (see Figure 3).

The Skylab HHMU will be evaluated with the back-mounted Automatically Stabilized Maneuvering Unit (ASMU) in place (Figs. 5 & 9). The HHMU incorporates one pusher and two tractor thrusters (Figure 6). Six degrees of freedom maneuverability is accomplished by orienting the thrust vector through the total center of gravity (CG) for translation and offset from the CG for rotation. The ASMU serves as a support module for HHMU evaluation. Propellant is supplied from the ASMU through an umbilical.

The HHMU mode will evaluate man's maneuvering capability with a simple, lightweight, and completely manual hand held propulsion device to provide translational and rotational acceleration along and/or about the X, Y, and Z axes. The crewman is required to visually determine his attitude and attitude rates. When maneuvers are made, he must properly orient the HHMU and manually operate a throttle valve trigger for the desired thrust level and duration.

The Skylab HHMU characteristics are shown in Table V.

The ASMU (Figure 5) is a back-mounted unit designed to evaluate the direct mode in addition to the HHMU mode. It contains multiple fixed position thrusters located to produce translational forces through the total system center of mass and to produce pure rotational couples about each of the three body axes. The unit provides powered translational and rotational command maneuvering capabilities in six degrees of freedom by means of

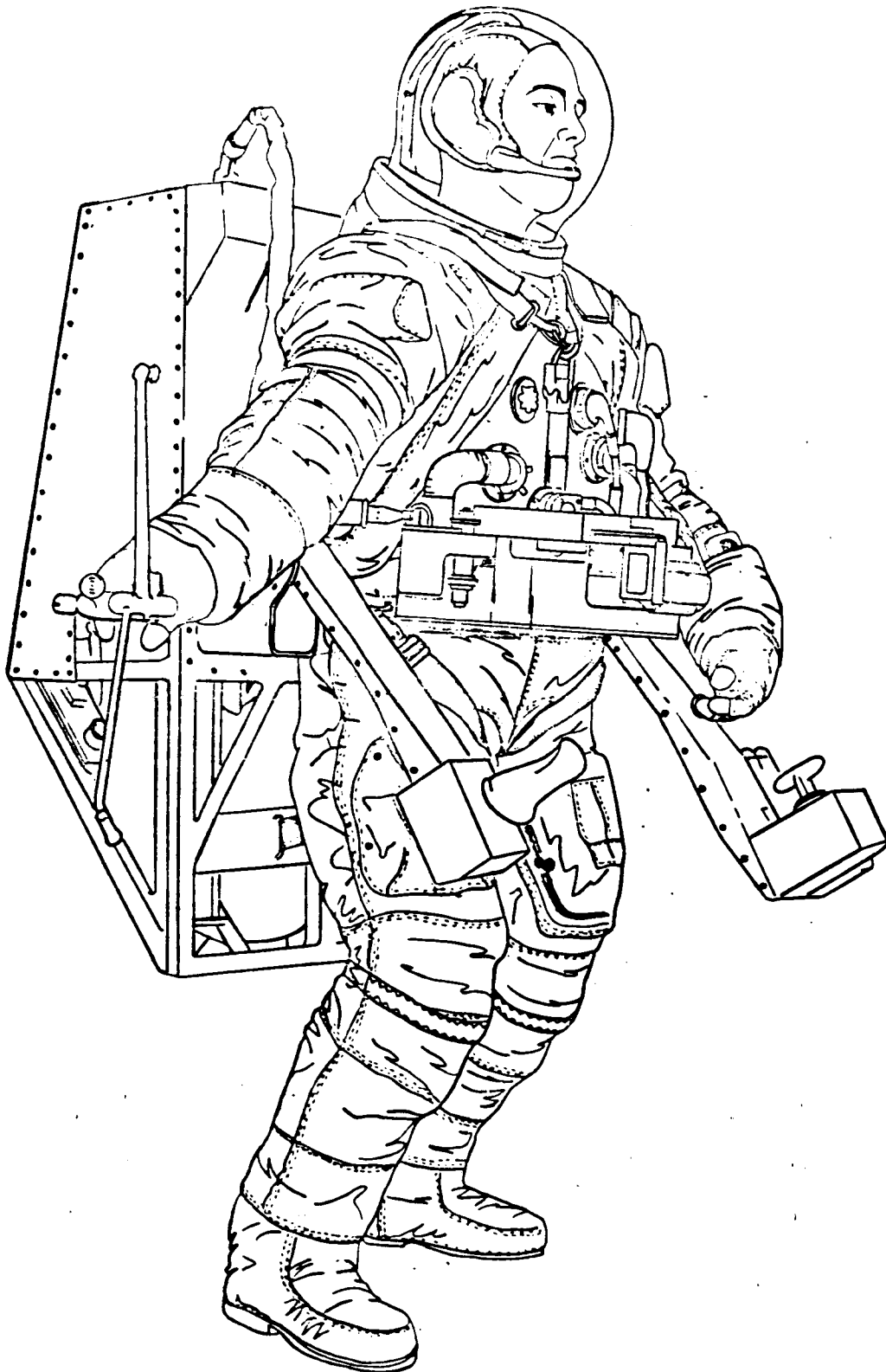


FIGURE 5 SKYLAB AUTOMATICALLY STABILIZED MANEUVERING
UNIT WITH HAND HELD MANEUVERING UNIT

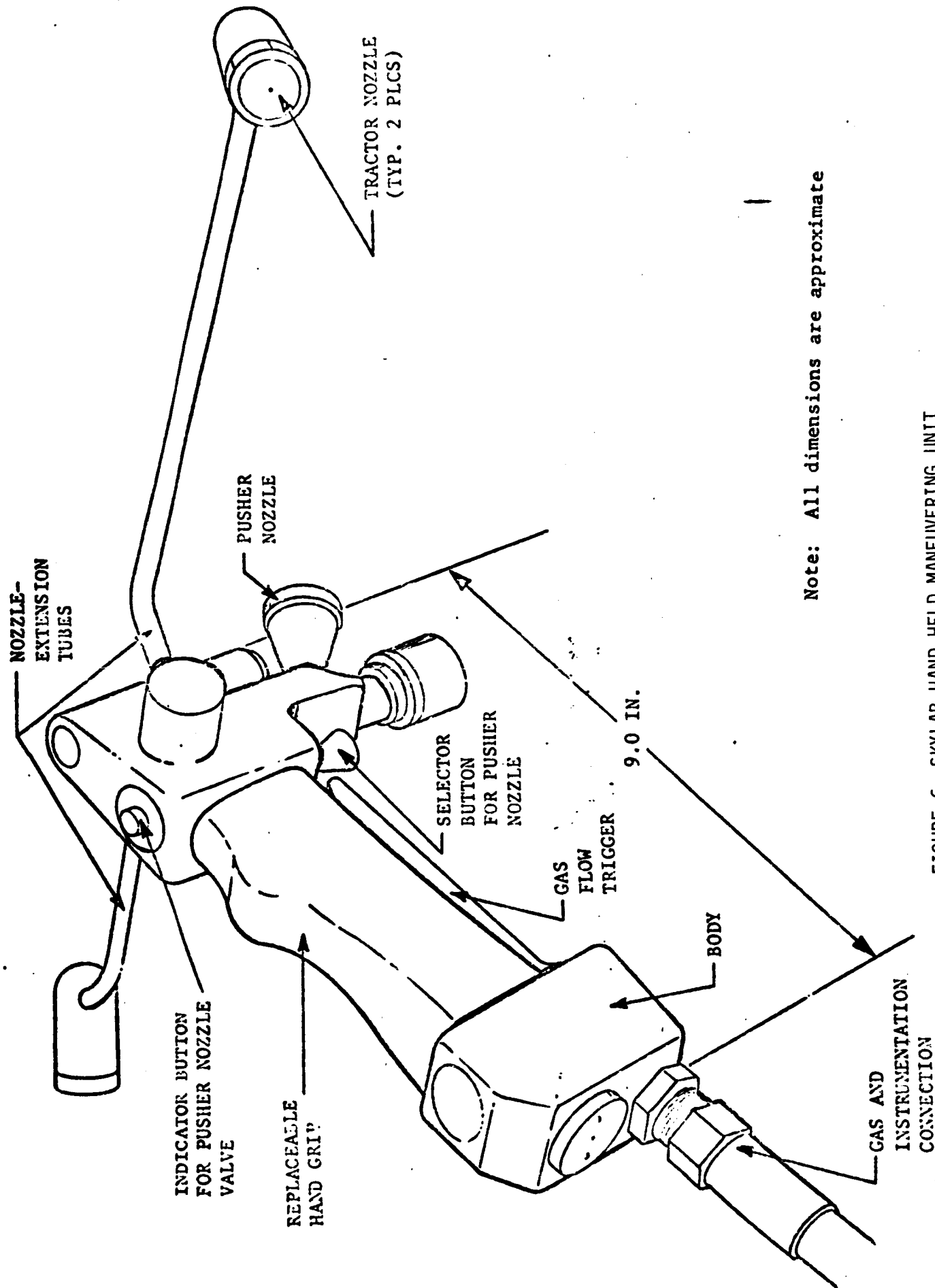


FIGURE 6 SKYLAB HAND HELD MANEUVERING UNIT

TABLE V SKYLAB AUTOMATICALLY STABILIZED MANEUVERING
UNIT CHARACTERISTICS

Weight (lbs.)	256.5
Volume (ft. ³)	20
Dimensions (in.)	24 x 24 x 60
Propellant, gas	Nitrogen
Propellant weight (lbs.)	11.2/Tank
Stowage tank pressure (psia)	3000
Regulated pressure (psia)	145 \pm 10
Propellant supply subsystem weight (lbs) . . .	57.4 (charged)
Propellant flow rate to thrusters (lbs/sec.) .	0 to 0.095
Operational time per tank (min.)	30 (approx.)
Quick disconnect force requirements (lbs) . .	25 (max.)
Power, battery	+ 28 vdc, 6 ampere-hours

fourteen thrusters centered about the overall system center of mass. The ASMU thruster orientation is shown in Figure 7.

The direct mode will evaluate man's maneuvering capability with a backpack maneuvering unit without automatic attitude stabilization. It provides translational hand controllers along and about the X, Y, and Z body axes. The hand controllers employ the same control logic as is used in the Apollo spacecraft. Constant angular acceleration is obtained through thruster firing when the rotational hand controller angle exceeds deadband threshold (± 0.5 degrees). Constant linear acceleration is obtained by continuous thruster firing when the translational hand controller exceeds deadband threshold. Acceleration command is used for rotation and translation. The Skylab ASMU characteristics are shown in Table VI.

TABLE VI SKYLAB HAND HELD MANEUVERING UNIT CHARACTERISTICS	
Weight of propellant (lbs)	11.2/Tank
HHMU weight (lbs).	3.0
Propellant (gas)	Nitrogen
Thrust, tractor or pusher (lbs).	0 to 3.00 \pm 0.25
Specific impulse calculated (sec)	58 \pm 2
Total impulse (lbs/sec).	650/Tank
Total available velocity increment (ft/sec).	53
Trigger preload (lbs).	-
Trigger force at maximum thrust (lbs).	-
Storage tank pressure (psia)	3000
Regulated pressure (psia).	145 \pm 10
Nozzle area ratio (designed for 5 psia environment, tractor/ pusher)	2.75/3.02

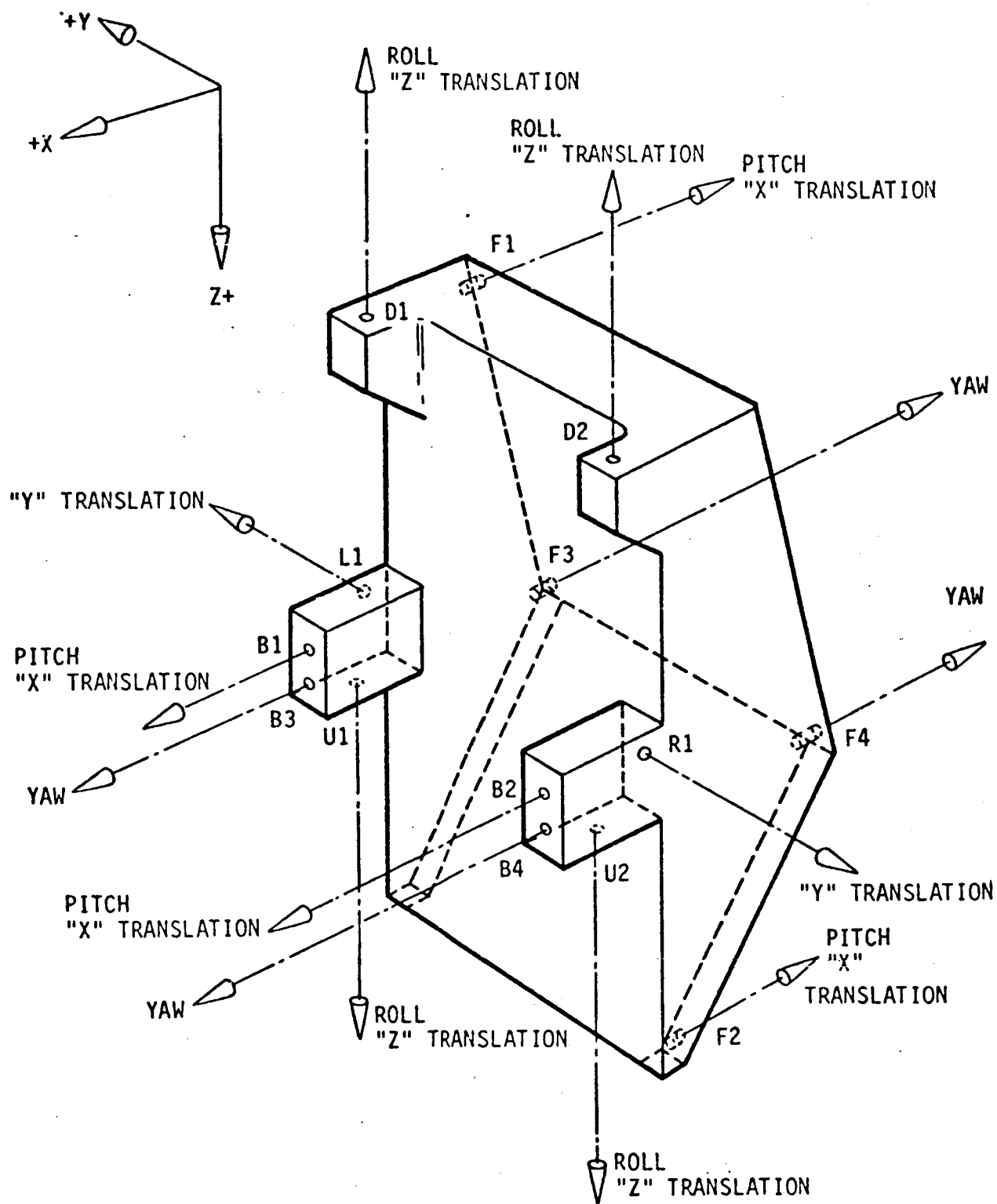


FIGURE 7 SKYLAB ASMU THRUSTER ORIENTATION

A gaseous nitrogen powered prototype called a Self Maneuvering Unit (SMU), backpack maneuvering unit, with the capability of operating without attitude hold was tested by the U.S. Air Force starting in 1962. The flight test program demonstrated that a maneuvering unit of this type was feasible and would meet the requirements of manned operations in the weightlessness of space (Ref. 5). Gaseous nitrogen powered training versions of the Gemini AMU, discussed in 1.1.2.1.1.1, were flown without attitude hold, in zero-g aircraft and on frictionless platforms in preparation for the Gemini missions. This training helped establish that the Gemini AMU would operate as designed under space conditions.

1.1.2.1.1.2 Concept 2

The Foot Controlled Maneuvering Unit experiment (T020), to be conducted within the Skylab Orbital Workshop, will evaluate the use of a relatively simple astronaut maneuvering device for future crew and cargo transfer applications. The maneuvering device (Figure 8) will allow the crewman to control his attitude about three axes and to translate along the vertical body axis. The unit will provide "hands-free" operation for task performance and cargo transfer.

The FCMU employs foot-operated controls, unbalanced-attitude thrusters and translational thrusters acting along the near-vertical body principle axis. The unit is straddled by the crewman while performing the maneuvering activities.

Characteristics of the FCMU are shown in Table VII.

1.1.2.1.1.3 Concept 3

The SMU and gaseous nitrogen powered Gemini Training AMU mentioned in 1.1.2.1.1.1 were tested with automatic attitude hold, demonstrating

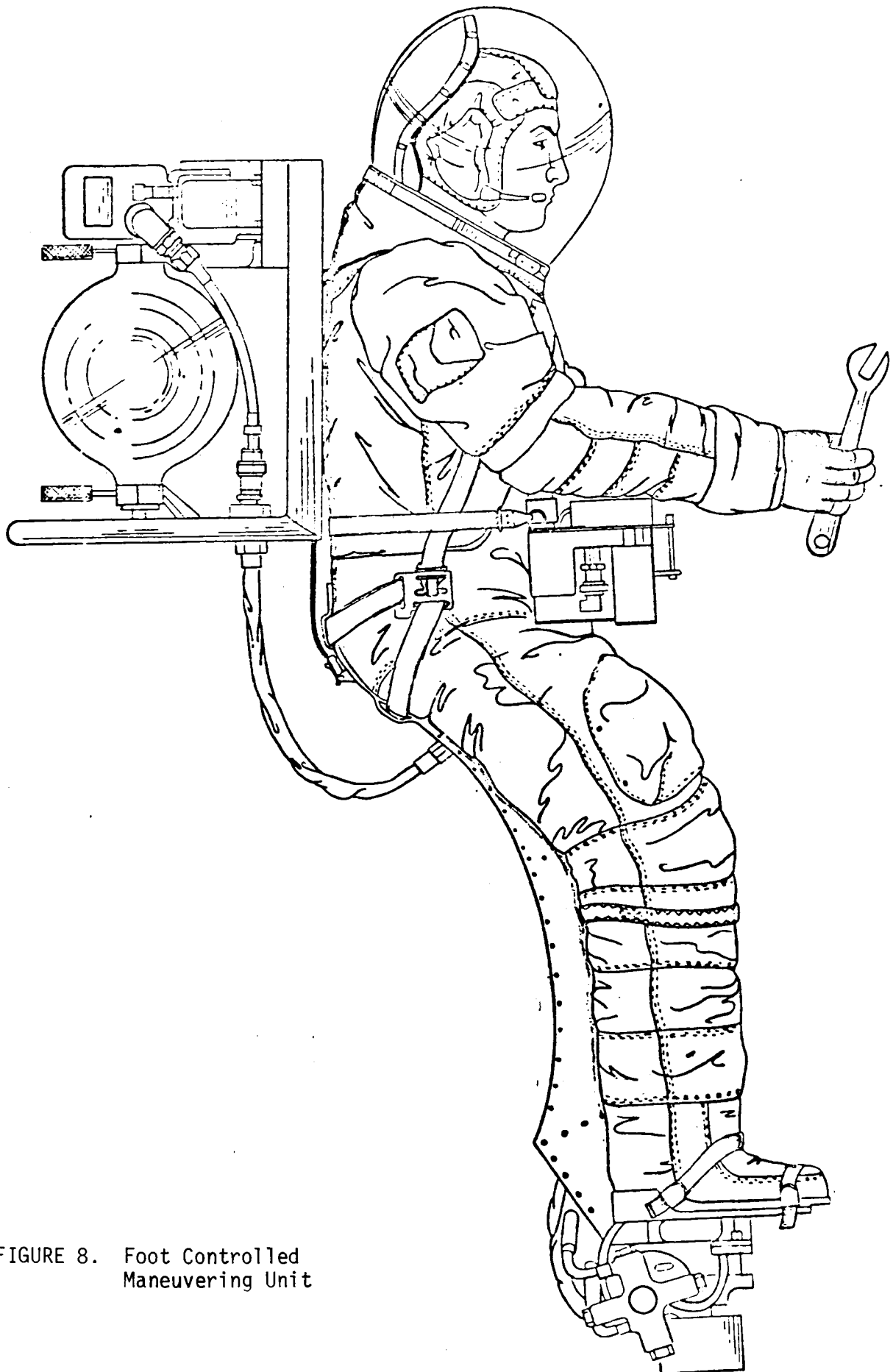


FIGURE 8. Foot Controlled
Maneuvering Unit

TABLE VII FOOT CONTROLLED MANEUVERING UNIT CHARACTERISTICS

Weight (lbs)	59.1**
Stowage Volume (ft ³)	23 (approx.)
Stowage dimensions (in.)	25.5 x 28 x 54
Propellant, gas*	Nitrogen
Propellant weight (lbs)*	11.2/Tank
Stowage tank pressure (psia)*	3000
Regulated pressure (psia)*	145 \pm 10
Propellant supply subsystem weight (lbs)	57.4 (charged)
Propellant flow rate to thruster (lbs/sec)*	0 to 0.095
Thrust (lbs)	0.3 to 1.0
Power, battery*	+28 vdc, 6 ampere-hours
Translational acceleration (ft/sec ²)	0.1
Attitude acceleration (°/sec ²)	4

*The PSS and battery are also used on Skylab experiment M509.

**Does not include weights of propellant supply subsystems or battery.

that translation and rotation control was much easier when attitude hold was used. The ASMU described in 1.1.2.1.1.1 will be tested in the rate gyro mode on the Skylab Program. The rate gyro mode employs the same thruster configuration and acceleration characteristics as the direct mode in Concept 1 but has automatic stabilization and attitude hold that is provided through rate gyro sensors and associated control electronics. Attitude rates are proportional to hand controller position up to 20 degrees per second. Upon return of the hand controller to the neutral position, rotational rates are reduced to less than ± 2 deg/sec with an attitude hold automatically maintained to within a deadband of ± 4.0 degrees.

1.1.2.1.1.4 Concept 4

This concept takes on the form of the MWP, Concept 18, discussed in 1.1.2.1.1.18 and shown in Figures 12 and 13. It would utilize

high pressure gaseous propellant and rate gyros, instead of Hydrazine propellant and control moment gyros used in 1.1.2.1.18.

1.1.2.1.1.5 Concept 5

This concept would be Concept 2 discussed in 1.1.2.1.1.2, with rate gyros and control logic added to fire thrusters for automatic attitude hold.

1.1.2.1.1.6 Concept 6

This concept is Concept 17, the Skylab ASMU or the Shuttle AMU, discussed in 1.1.2.1.1.17 with the thrusters instead of the CMG used for rotational maneuvering.

1.1.2.1.1.7 Concept 7

This concept is the same as Concept 4 discussed in 1.1.2.1.1.4, with CMG added for attitude hold.

1.1.2.1.1.8 Concept 8

This concept is Concept 2, the Skylab FCMU discussed in 1.1.2.1.1.2, with CMG added for attitude hold.

1.1.2.1.1.9 Concept 9

This concept was developed and qualified for flight as a Hydrazine HHMU on the Gemini program. The unit is currently in storage. There are no known plans for further tests.

1.1.2.1.1.10 Concept 10

This concept is the same as Concept 2, the FCMU described in 1.1.2.1.1.2, except a monopropellant, with a higher specific impulse is used instead of compressed gas.

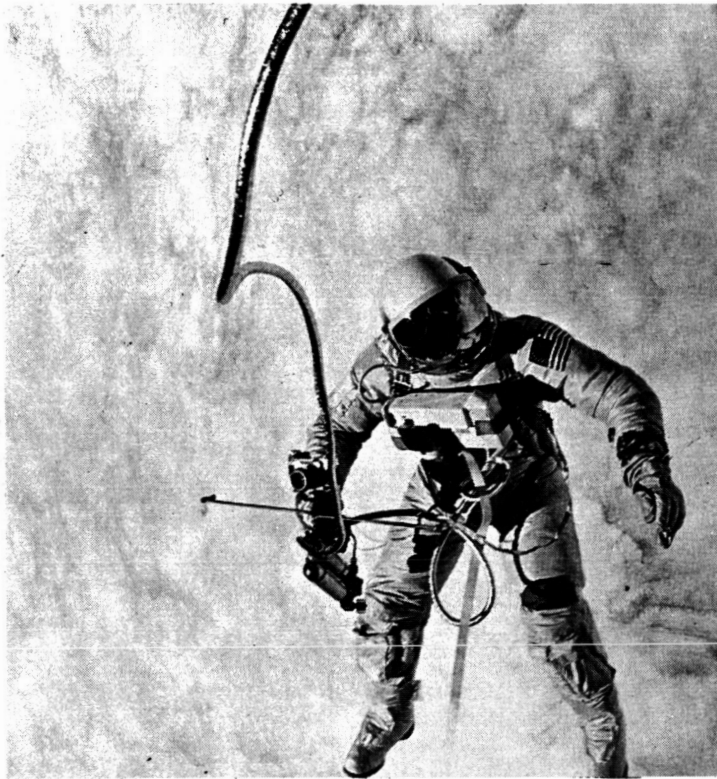
1.1.2.1.1.11 Concept 11

This concept was developed and qualified for flight by LTV for the Air Force as the Gemini AMU. The Gemini Astronaut Maneuvering Unit (AMU) was a backpack device which contained the necessary systems to permit an extravehicular crewman to maneuver in space independent of spacecraft systems. The AMU was carried on Gemini IX-A under Air Force Experiment D012 and was originally planned to be carried on Gemini XII. However, the Gemini XII flight plan was subsequently revised, and the AMU was not included. Although a maneuvering evaluation was not accomplished in orbit, a large effort was expended in preparing for the evaluation. There are no known plans for further tests.

The Gemini AMU, shown in Figure 9, was a compact unit consisting of a basic structure and six major systems: propulsion, flight control, oxygen supply, power supply, alarm, and communications.

The structure consisted of the backpack shell, two folding sidearm controllers, and folding nozzle extensions. The hydrogen peroxide thrusters were located in the corners of the structure to provide controlling forces and moments about the center of gravity of the AMU-crewman combination.

As part of the donning task, the crewman unfolded the nozzle extensions and controller arms into position. The control handles by which the crewman could introduce translation and attitude commands were on the front of the controller arms. The left-hand controller provided translation commands; the right-hand controller provided attitude control. Manual and automatic three-axis attitude control and stabilization, and manual translation in two axes was available. Mode selection was available to select either automatic or manual attitude control and stabilization. On each controller arm there was a thermal shield for protection of the pilot's gloves



GEMINI HAND HELD MU



ASTRONAUT MANEUVERING UNIT



ASMU

FIGURE 9 PHOTOGRAPHS OF ASTRONAUT MANEUVERING DEVICES

from the thruster plume heat.

The nozzle extensions directed the exhaust plumes from the upper forward-firing thrusters away from the helmet and shoulders of the suit. Primary and alternate sets of thrusters were provided, as shown in Figure 10. Each utilized eight thrusters; two forward, two aft, two up and two down. The forward-firing and aft-firing thrusters were operated as balanced pairs for translation forward and aft and for pitch and yaw control. The up-firing and down-firing thrusters were used for translation vertically and for roll control. The alternate system used entirely separate forward-firing and aft-firing thrusters but used the same thrust chambers for up and down

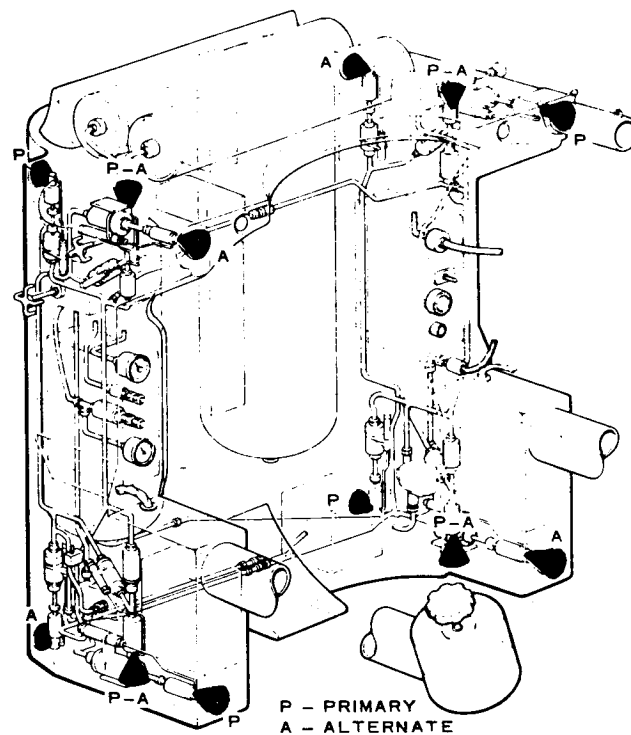


FIGURE 10. GEMINI AMU Thruster Arrangement

thrusting. However, separate control valves were used in the alternate system for the up, down, and roll commands.

The oxygen supply system provided oxygen to the Extravehicular Life Support System (ELSS) chestpack. The power supply provided electrical power to the AMU for the mission duration with a 100-percent reserve capacity. The alarm system gave both the EVA crewman and the IV monitors an audible warning when certain critical out-of-tolerance conditions were present. Both telemetry and voice communications were provided.

The general characteristics of the Gemini AMU are shown in Table VIII.

TABLE VIII GEMINI ASTRONAUT MANEUVERING UNIT CHARACTERISTICS	
AMU weight (lbs)	168 (wet)
Weight of propellant (lbs)	24 (min)
Propellant (fuel)	H ₂ O ₂
Specific impulse calculated (sec)	169
Total impulse (lbs/sec)	3600
Storage tank pressure (psia)	0-590
Chamber pressure (psia)	145
Nozzle expansion ratio	40:1
Thrust level per thruster (lbs)	2.3 + .03
Dimensions (in)	35x24x17
Life support oxygen (lbs)	7.3

1.1.2.1.1.12 Concept 12

This concept takes on the form of Concept 18, the MWP described in 1.1.2.1.1.18 and shown in Figures 12 and 13. It would utilize rate gyros and thrusters instead of the CMG for attitude hold and rotational maneuvering.

1.1.2.1.1.13 Concept 13

This concept takes the form of Concept 2, the Skylab FCMU discussed in 1.1.2.1.1.2. Rate gyros and thrusters are added for attitude

hold and a monopropellant fuel.

1.1.2.1.1.14 Concept 14

This concept is the same as Concept 11, the Gemini AMU discussed in 1.1.2.1.1.11, with CMG for attitude hold instead of rate gyros and thrusters.

1.1.2.1.1.15 Concept 15

This concept is the same as Concept 18, the MWP discussed in 1.1.2.1.1.18 with the CMG used only for attitude hold.

1.1.2.1.1.16 Concept 16

This concept takes the form of Concept 2, the Skylab FCMU discussed in 1.1.2.1.1.2, with CMG for attitude and a monopropellant fuel.

1.1.2.1.1.17 Concept 17

The ASMU described in 1.1.2.1.1.1 will be tested on the Skylab program in the control moment gyro (CMG) mode. In this mode, attitude control is provided through momentum exchange instead of mass expulsion. The angular momentum of the CMGs is sufficient to passively resist small external torques and to produce proportional attitude rates on command. Actuation of the rotational hand controller results in a torque applied to the appropriate gyro assembly to produce rotation about the desired axis. The rate of rotation (up to 5°/sec) is proportional to the displacement of the controller. If the CMGs become saturated by external torques, the thrusters are automatically commanded by internal electronics to apply torque in the proper direction to desaturate the gyros. Acceleration command is again used for translation.

An AMU test is planned for the Shuttle program. The Shuttle AMU shown in Figure 11 is a back-mounted system with multiple fixed-position thrusters. Six Control Moment Gyros (CMG), arranged in pairs along the

three body axes, provide automatic stabilization and attitude control. A cold-gas reaction control system is used to provide thrust for translation and to produce restoring torques for CMG momentum dumping. The AMU has electrical power, data communication, gas supply, and life support subsystems to allow operation of the unit independent of umbilicals to the spacecraft. A hand controller is used to provide control signals to torque the gyros for changing attitude. A separate hand controller is used to activate the thrusters for translational control.

Interchangeable high-pressure gas bottles are used for supplying the oxygen for the crewman life support system (LSS) and propulsion gas. Shuttle AMU system characteristics and performance requirements are listed in Table IX.

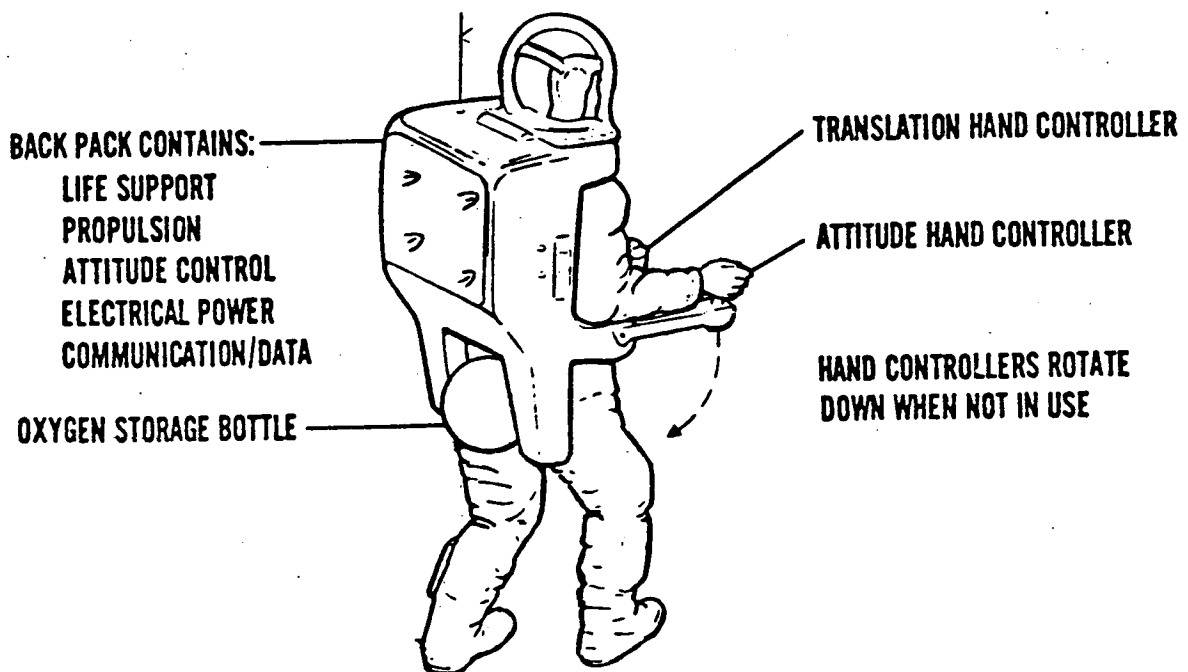


FIGURE 11. Shuttle Astronaut Maneuvering Unit
(from Ref. 4)

TABLE IX SHUTTLE ASTRONAUT MANEUVERING UNIT CHARACTERISTICS

Weight (lbs)	190
Volume (ft. ³)	20
Dimensions (ft.)	2 x 2 x 5
Support equipment weight (lbs.)	60
Support equipment volume (ft. ³)	3.4
LSS/propellant tank weight (lbs.)	75
Propellant gas	Oxygen
Regulated pressure to thruster (psia)	165
Power (watts)	330 (700 peak)
Data requirements (bits/sec)	5000 (3000 min.)
o Voice	Yes
o TV Film	Yes

1.1.2.1.1.18 Concept 18

A Maneuvering Work Platform (MWP) test is planned for the Shuttle program (Ref. 4). The Shuttle MWP consists of four basic elements, (1) a forward control module, (2) an aft module, (3) a removable tools/spares module, and (4) a collapsible cargo frame. These four elements allow the MWP to take on three basic configurations: (1) a minimum configuration, containing only the fore and aft modules; (2) a nominal configuration containing the fore, aft, and tools/spares module; and (3) an expanded configuration, where the cargo frame replaces the tools/spares module. Extending along each side of the forward module are hinged "running boards" which act as scaffolds at the work site. Figures 12 and 13 illustrate the three configurations (Ref. 6).

The forward control module contains all of the flight controls and displays and the controls for the anchoring/grappler arms. Three of these arms are arranged in a triangular pattern on the forward face of the module. In addition, radar antennas, RCS thrusters, a circuit breaker panel, an emergency stub antenna, work lights and running lights are provided. An

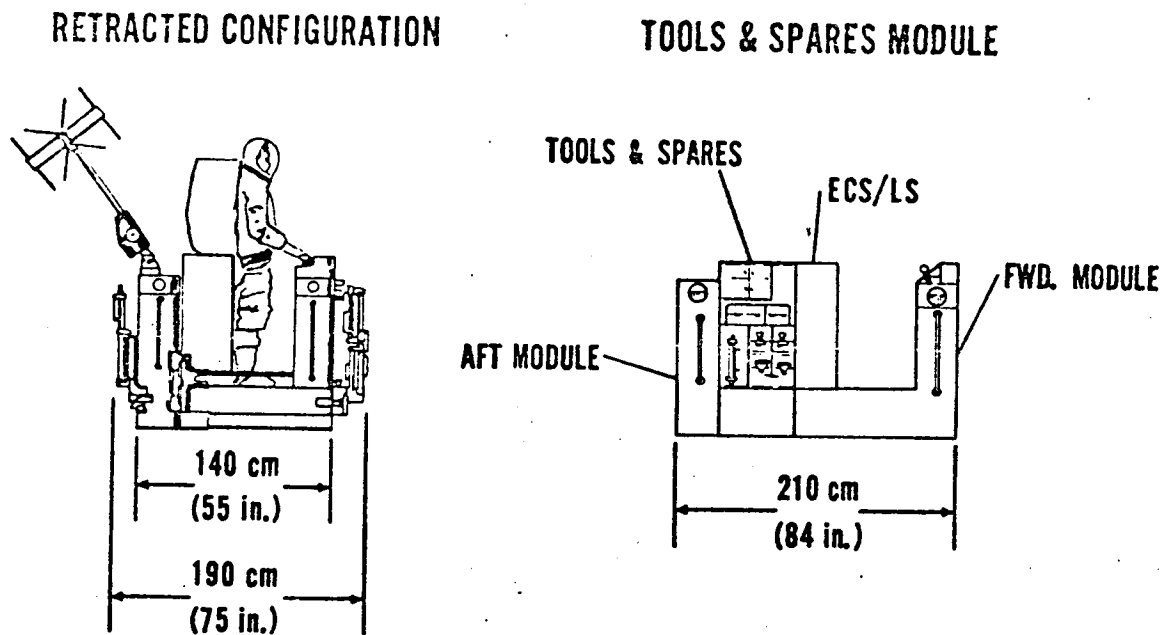


FIGURE 12. Maneuvering Work Platform in the Retracted Configuration (from Ref.6)

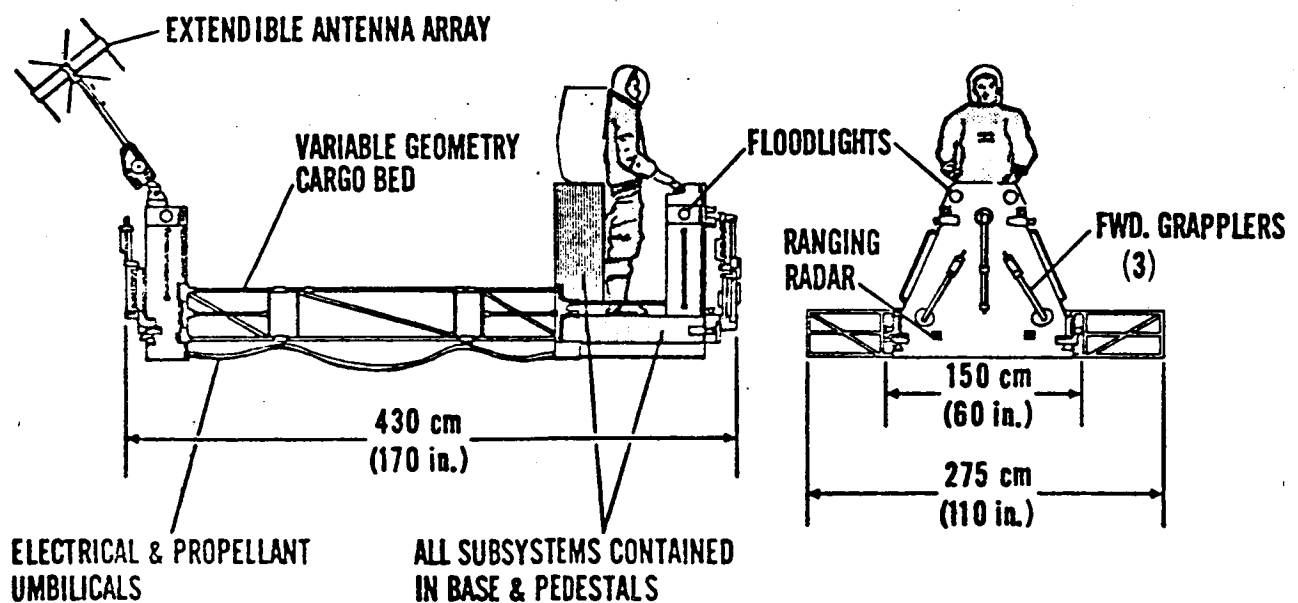


FIGURE 13. Maneuvering Work Platform in the Extended Configuration (from Ref.6)

environmental control system/life support (ECS/LS) compartment is anchored to the module base and incorporates body restraints for the crewman.

The top surface of the ECS/LS compartment provides a mount to secure the crewman's portable life support system, or AMU, which is used to man the MWP from the parent spacecraft.

The aft module supports the aft grapppler, the aft propulsion thrusters, an an extendible antenna. This antenna, which is controllable in azimuth and elevation, can be extended to a length of 20 ft. to maintain line-of-sight communication with the parent spacecraft around an intervening work site.

The tools/spares module is designed in two sections with spare parts bins below and the tool box above. Covers for the tool compartment hinge to provide access; the upper covers form tool racks and the lower ones serve as working surfaces when open. The upper center panels of the tool bench serve for mounting gages, meters, test plugs and jacks for diagnostic and checkout equipment. The tool box will be accessible from either side, with the crewman restrained in a standing attitude on the "running boards".

The variable-geometry cargo frame is assembled without tools by means of quick-disconnect structural joints. The frame is made of interchangeable truss sections fabricated from welded aluminum tubing. Each section terminates in one-half of a sleeve-lock structural joint capable of transmitting structural loads in all directions. With the removable side sections, the frame can be made approximately 100 in. square. Removal of these sections shortens the frame to 50 in. long. MWP physical characteristics and performance requirements are listed in Table X.

TABLE X MANEUVERABLE WORK PLATFORM CHARACTERISTICS

Weight (lbs.)	1600
Volume (ft. ³)	140
Dimensions (ft.)	5 x 4 x 8
Support equipment weight* (lbs.)	2006
Support equipment volume* (ft. ³)	186
Propellant, gas	Oxygen
Power (watts)	580 (980 peak)
Data requirements (bits/sec).	8000 (5000 min.)
• Voice	Yes
• TV Film.	Yes

*Includes weight and volume for AMU, teleoperator system, camera and data displays.

Flight control evaluations of the MWP will initially be conducted untethered in close proximity of the spacecraft. Remote maneuvers will then be performed to permit evaluation of guidance, navigation, and rendezvous operations. As in the AMU evaluation program, the MWP experiment will be performed during daylight and night side conditions.

1.1.2.1.1.19 Concept 19

This concept takes the form of Concept 2, the Skylab FCMU discussed in 1.1.2.1.1.2, with monopropellant fuel and CMG for attitude hold and rotational maneuvering.

1.1.2.1.2 Free Flying Maneuvering Unit Evaluations and Recommendations

The free-flying maneuvering units must provide for translating the 2000 feet minimum between vehicles in Scenario 7.

The Gemini AMU (Ref.21) was sized to provide 3600 lb-sec total impulse. This would allow an astronaut to translate to a maximum distance of 2000 feet and return with considerable reserve. The maneuvering work platform (Ref. 6) was to provide 45,000 lb-sec total impulse, 22,900 of

which was to allow an astronaut to translate 2 kilometers, or 7,460 feet, and return, 3 times. This allows approximately 1 lb/sec for 1 foot of range or 2000 lb/sec for one 2000 ft round trip. Allowing for reserve propellant supply this would bring the total impulse requirement to above 3000 lb/sec.

For purposes of evaluation, therefore, the free-flying maneuvering units will be sized to provide 3600 lb/sec total impulse.

Concepts 1 thru 8 utilize compressed gas for propulsion. From Table 53, Ref. 5, a 2000 lb/sec gaseous nitrogen propulsion system would weigh 100 lb and have a volume of 2.2 ft³. Scaling this system up to 3600 lb/sec would make the system weigh 180 lb and have a volume of 4 ft³. This is approximately equivalent to the Gemini AMU backpack which weighed 169 lb and had an enclosed volume of about 4 ft³, which was acceptable. However, for free-flying maneuvering units some life support equipment must be provided. To add this to the backpack would make a backpack too large to be practical, therefore all compressed gas, strap-on concepts (1,2,5,6, & 8) are eliminated from further consideration.

Concepts 9 thru 17 utilize a monopropellant for propulsion. Considering the free-flying maneuvering unit as a contamination source, the use of compressed gas for propulsion produces less contamination than monopropellants. Since the satellites to be serviced are contamination sensitive, all concepts utilizing monopropellants (9 thru 16) are eliminated from further consideration.

Concepts 17, 18 and 19 utilize control moment gyros (CMG) for automatic attitude hold and commanded roll, pitch and yaw rotation plus propulsion thrusters for command translation and CMG momentum dump. Again from the contamination standpoint, these concepts using CMG for

automatic attitude hold and commanded rotation, produce less contamination than concepts 4 and 7 using propulsion thrusters for those functions, therefore concepts 4 and 7 are eliminated from further consideration; but the compressed gas propulsion for commanded translation and CMG momentum dump is still desired for minimum contamination. Considering the utility of the unit, a maneuvering work platform which can transport tools, spare parts, checkout equipment, grapple and moderate supplies of life support expendables is more preferable than a strap-on backpack, tethered equipment and minimum supplies of life support expendables. The "ride on" work platform could also give an astronaut a greater feeling of well being in free-flight than would a "put on" backpack by providing aids for the orbiter in location and tracking of the free-flyer.

The remaining work platform concept, #18, is therefore recommended for use on the orbiter. The configuration would be similar to that shown in Figures 12 and 13. It uses compressed gas as a propellant for the thrusters. The thrusters are used for commanded translation and CMG momentum dump. CMG are used for commanded rotation and automatic attitude hold. Hand controllers are used to command translation and rotation.

1.1.2.2 Manipulators

Attached Manipulator Systems (AMS) are being developed for use on the orbiter. The AMS would be long, articulated manipulators used to deploy and retrieve payloads and satellites and berth two modules in the harsh environment of near-earth space. The operator would control the operation from the master station located in the pressurized crew compartment of the spacecraft.(Ref. 7) The AMS can be considered as a powered mobility aid for EVA. The AMS can transport EVA astronauts and cargo, and provide

a portable work platform for EVA astronauts. Several manipulator mobility aid concepts will be considered:

- 1) A standard cargo transfer end effector
- 2) A cage type crew transfer end effector
- 3) Work platform end effector for crew transfer, cargo transport, and worksite provisions.

1.1.2.2.1 Manipulator with a Standard Cargo Transfer End Effector

The AMS would have a standard end effector, such as one of the two shown in Figure 14, which would be capable of grasping and transporting all the anticipated sizes and shapes of cargo utilized by an EVA crewman on the orbiter. The arm length would have to be increased and another joint created if the cargo is to be transported to all worksites on the orbiter and docked payloads.

1.1.2.2.2 Manipulator With A Cage Type Crew Transfer End Effector

The AMS would have an end effector such as shown in Figure 15. The EVA crewman would enter the cage and be transported to the desired worksite. Umbilical services, if required, and manipulator positioning controls would be available at the cage. The arm length shown in Figure 14 would have to be increased and another joint created to reach all worksites on the orbiter and docked payloads.

1.1.2.2.3 Manipulator With Work Platform End Effector

The AMS would have an end effector such as shown in Figure 16. The EVA crewman would load his tool box, spare parts, and checkout equipment into the spaces provided, mount the work platform, be transported to the desired worksite, and dock with or attach work platform to the worksite structure. Umbilical services, manipulator controls, and floodlights would

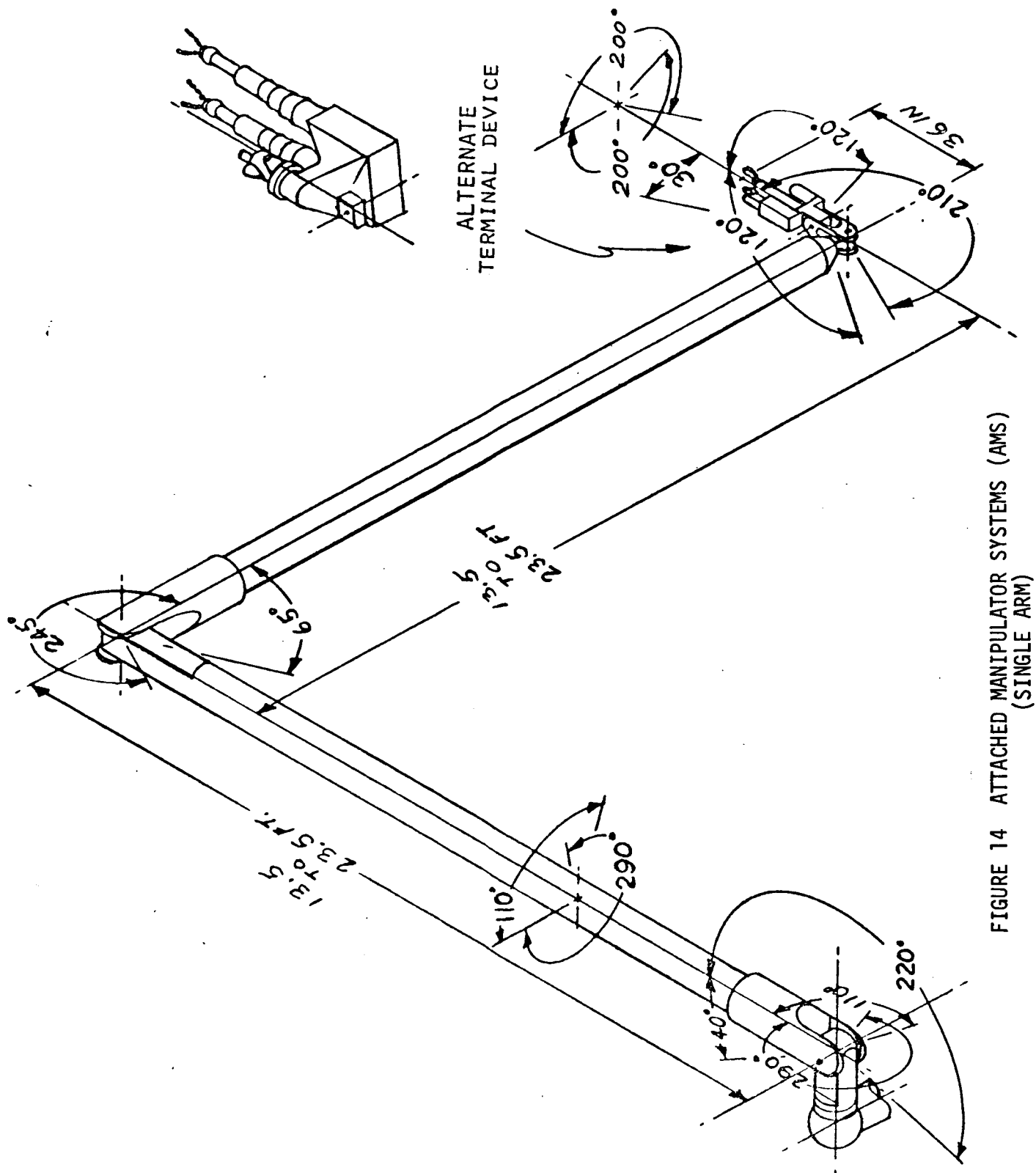


FIGURE 14 ATTACHED MANIPULATOR SYSTEMS (AMS)
(SINGLE ARM)

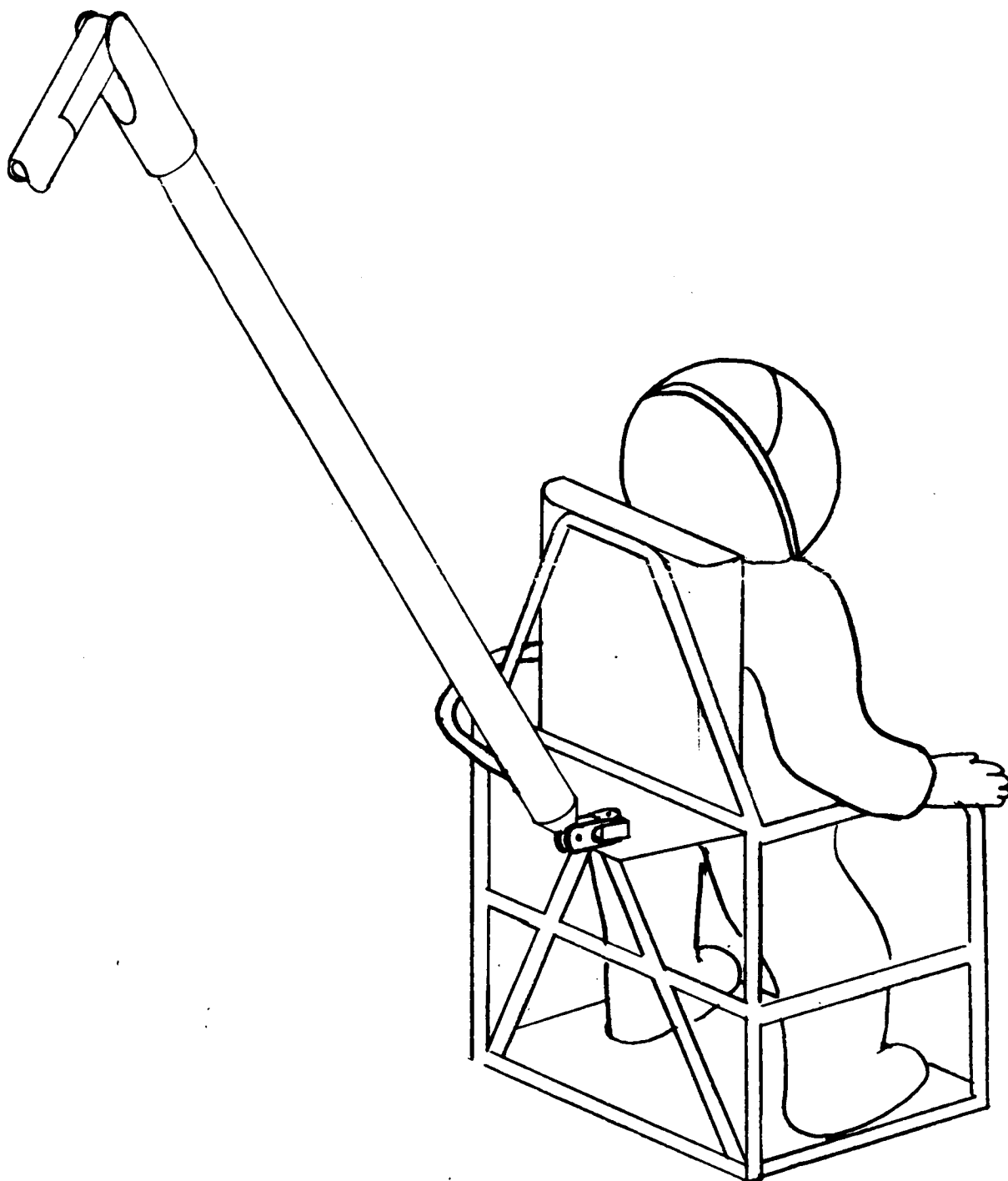


FIGURE 15. Manipulator with Crew Transfer Cage

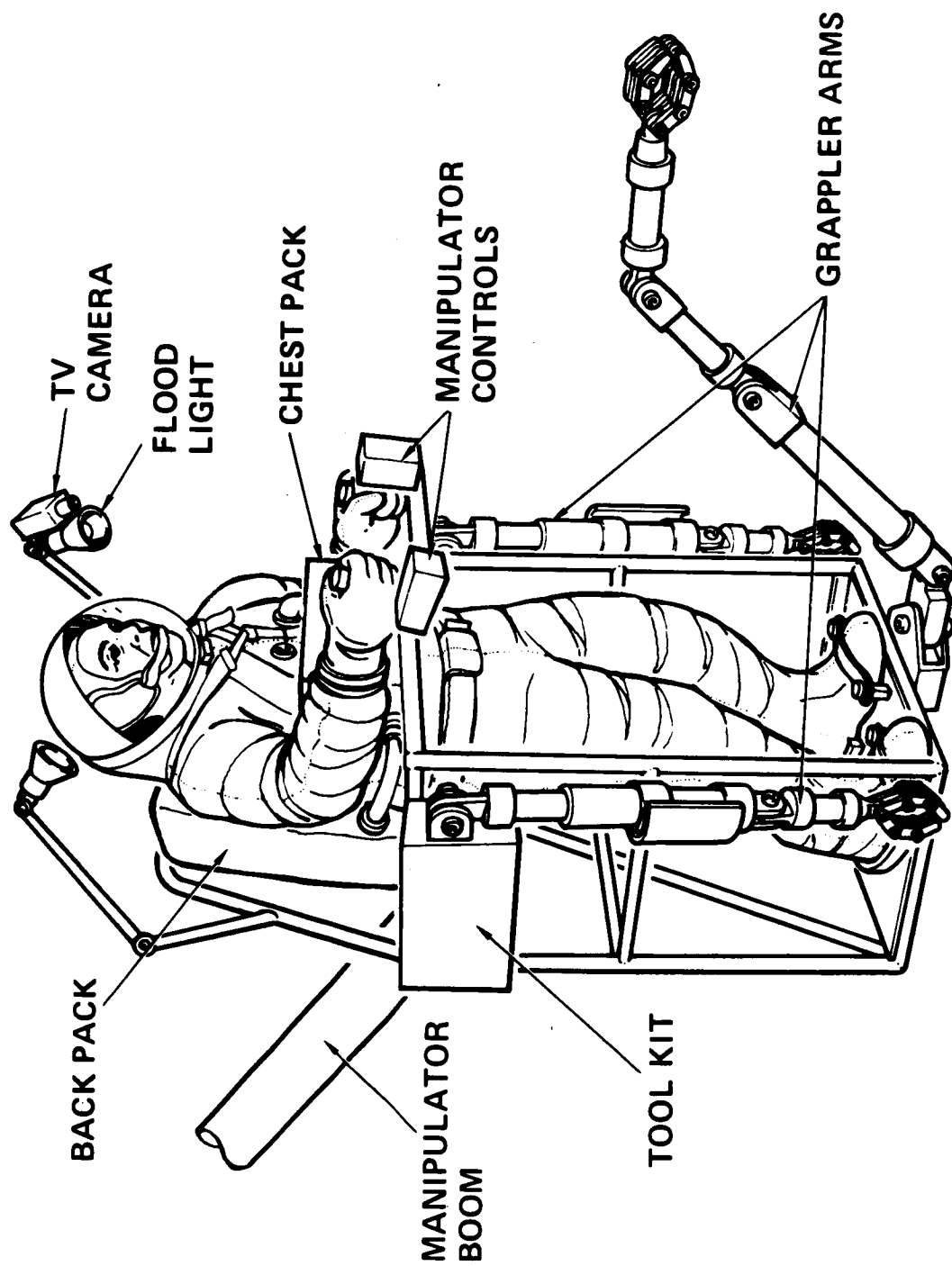


FIGURE 16. Manipulator with Work Platform

be available at the work platform. The arm length shown in Figure 14 would have to be increased and another joint created to reach all worksites on the orbiter and docked payloads.

1.1.2.3 Powered Cargo Transfer Devices

The manipulator discussed in 1.1.3.2 is one type powered cargo transfer device which will be used on the shuttle.

The Skylab program will use a powered cargo transfer device during the servicing of the Apollo Telescope Mount (ATM). Figure 17 is a drawing of the device, the Film Transfer Boom (FTB), Ref. 8. The FTB on Skylab is used to transfer ATM film and camera trees from workstation to workstation. The FTB has a deployment capability of 30 feet. It is electrically powered, with a manual backup mode.

1.1.3 Representative Translational Device Usage

Translational devices are required for the performance of all EVA and IVA, however each EVA and IVA is unique and creates unique requirements for translational devices. Sketches of the usage of the translational devices concepts for representative scenarios from Ref. 15 are presented and discussed. Those scenarios in Ref. 15 which are not included in this discussion contain similar situations which are discussed.

1.1.3.1 Maintenance of a Large Space Telescope (LST) Scenario #1

Figure 18 shows single handrails for manual crew translation for LST maintenance. The proper placement of the handrails allows access to all worksites. Temporary handrails are required for translation across the orbiter exterior thermal insulations surface and for translation into the telescope tube.

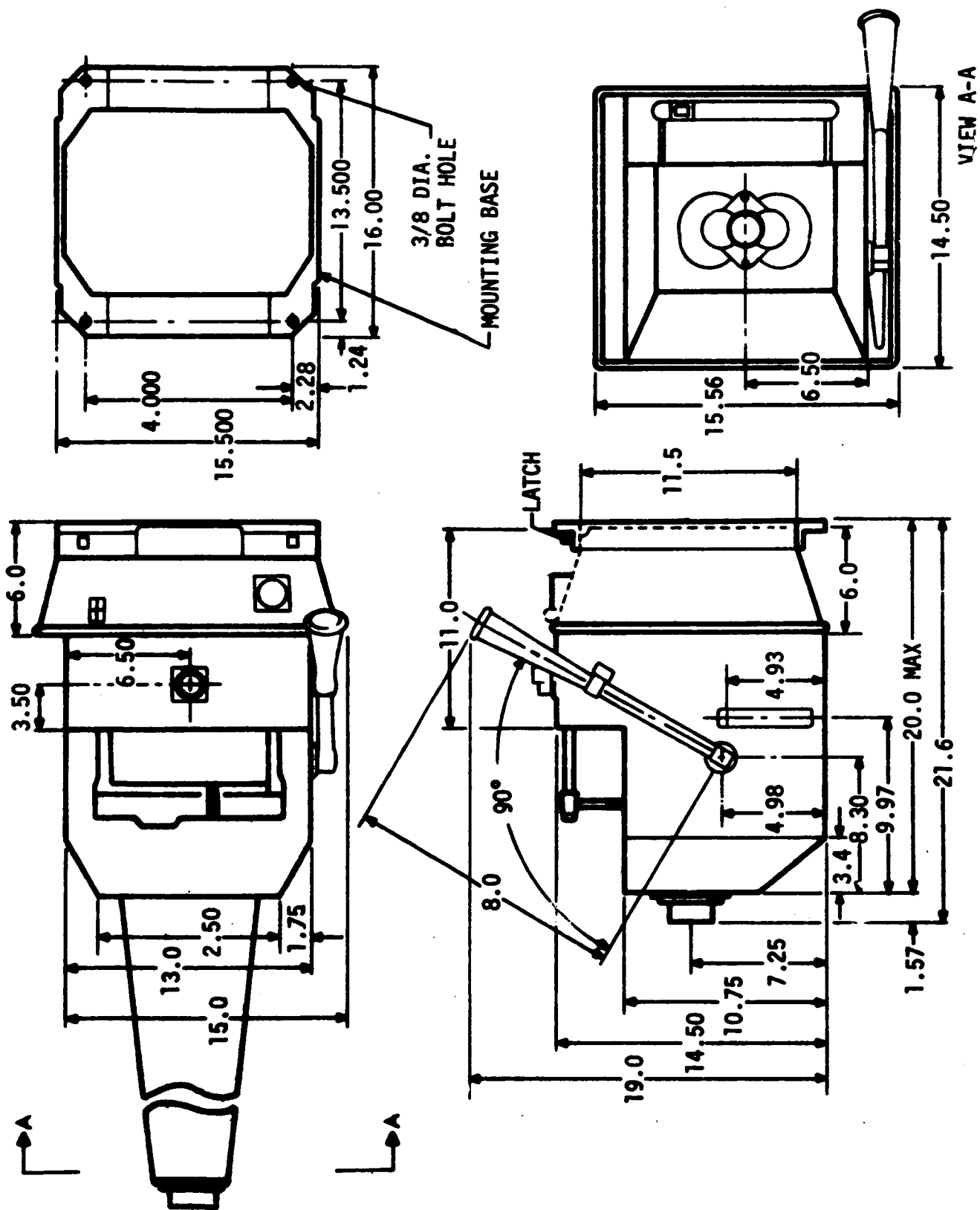


FIGURE 17. ATM Film Transfer Boom (from Ref. 8)

The use of electroadhesive devices would require the placement of a conductive surface along the paths to be followed, reference Figure 18, across the orbiter exterior thermal insulation surface, up the exterior surface of the service module and LST. A temporary pathway into the telescope tube and around the primary mirror would probably be required, due to the fragile nature of the structure in that area.

Figure 19 shows a maneuvering work platform (MWP) for crew translation for LST maintenance. Handrails, as shown, would be required for translation to the MWP stowage and checkout area. Handrails, as shown in Figure 18, would be required for translating into the telescope tube.

Figure 20 shows a manipulator with an end effector for crew transfer for LST maintenance. The manipulator end effector would be brought to the area of the airlock opening by remote control, the astronaut would mount the end effector directly from the airlock opening, eliminating the need for handrails in this area. Handrails, as shown in Figure 18, would be required for translating into the telescope tube. The manipulator arms as they now exist (max. 50 feet) would not be long enough to reach the aperture end position shown. A minimum of approximately 10 feet of additional length would be required plus an additional joint would be required to attain the position required.

1.1.3.2

EVA/IVA Support of An Earth Observation Sortie

Scenario #2

Figure 21 shows single handrails for support of an Earth Observation Sortie. Temporary handrails are required for translation across the orbiter exterior thermal insulation surface. The figure does not show provisions for access to the payload bay with the sortie lab rotated into the stowed

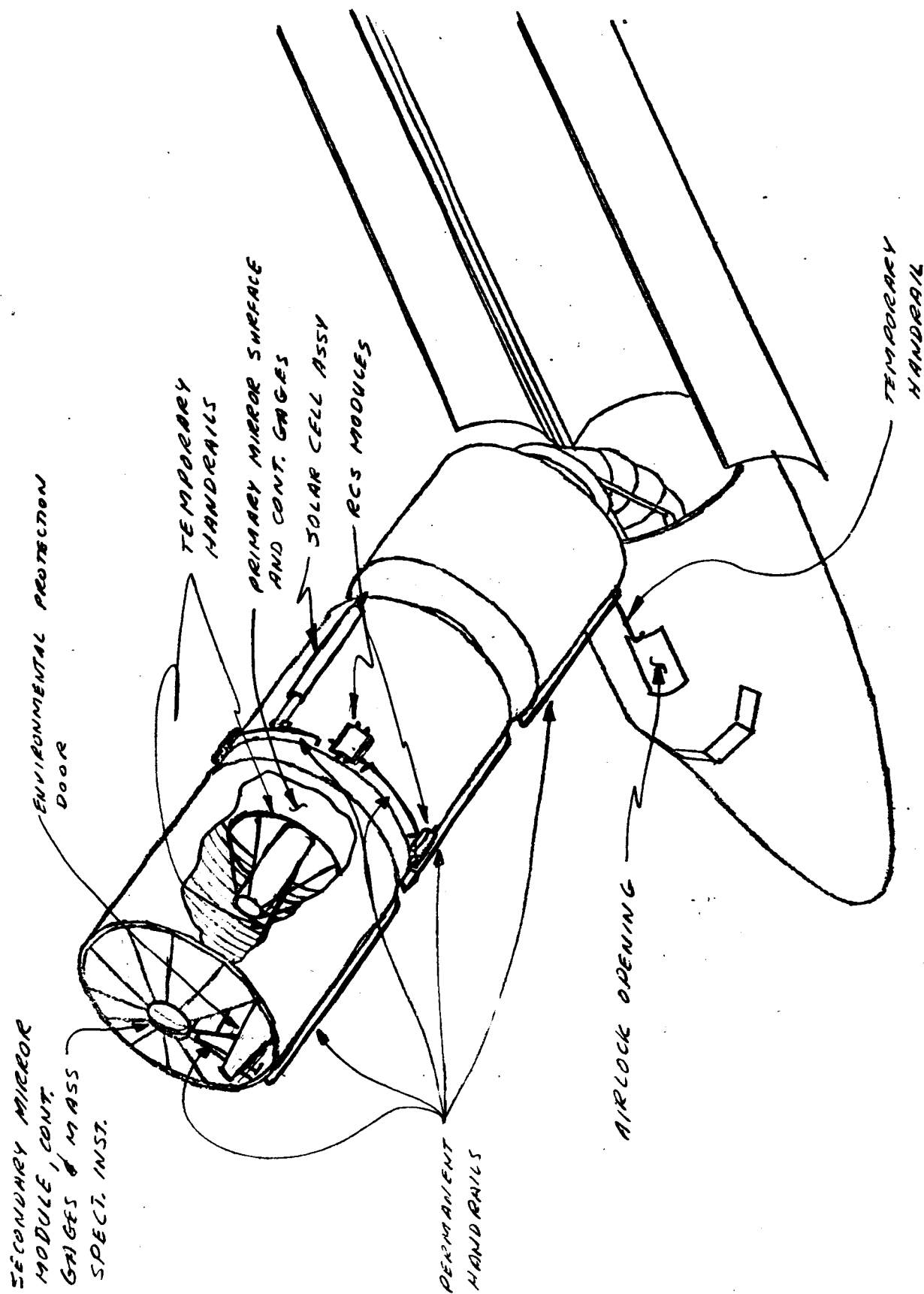


FIGURE 18 HANDRAILS CONCEPT FOR SCENARIO #1-LST MAINTENANCE

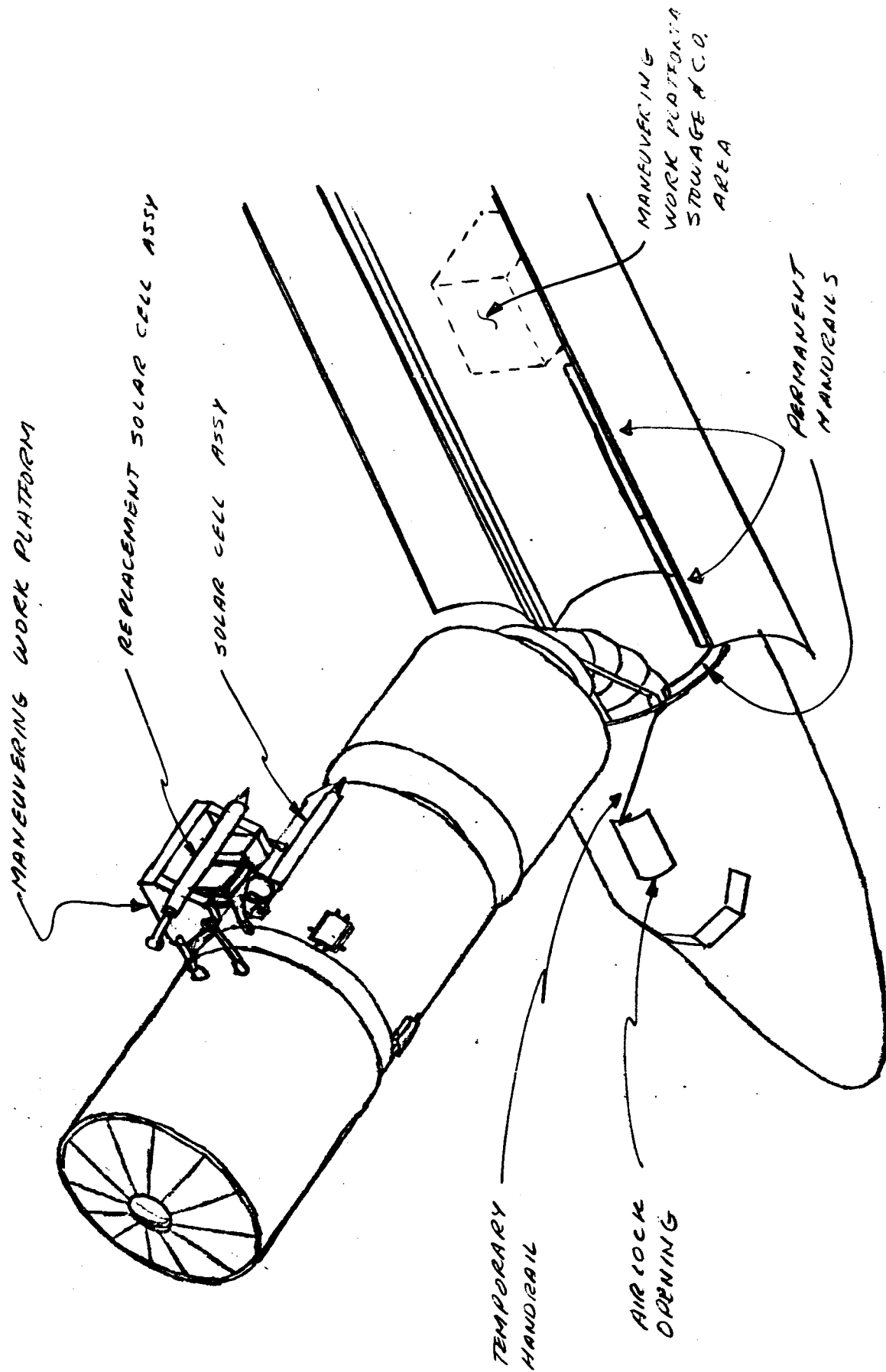


FIGURE 19 MANEUVERING WORK PLATFORM FOR SCENARIO #1-LST MAINTENANCE

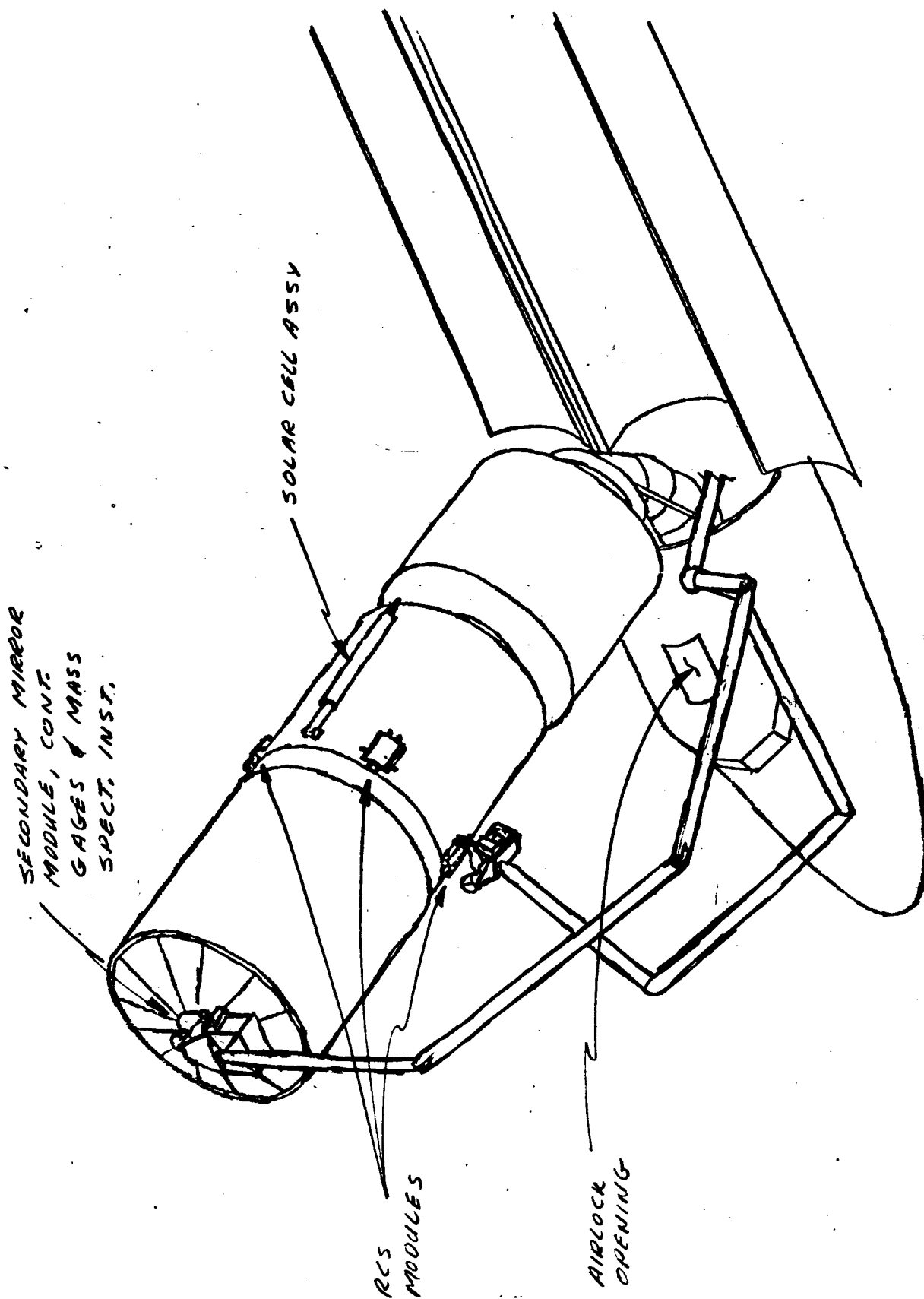


FIGURE 20 MANIPULATOR WITH CREW TRANSFER END EFFECTOR FOR SCENARIO #1-LST MAINTENANCE

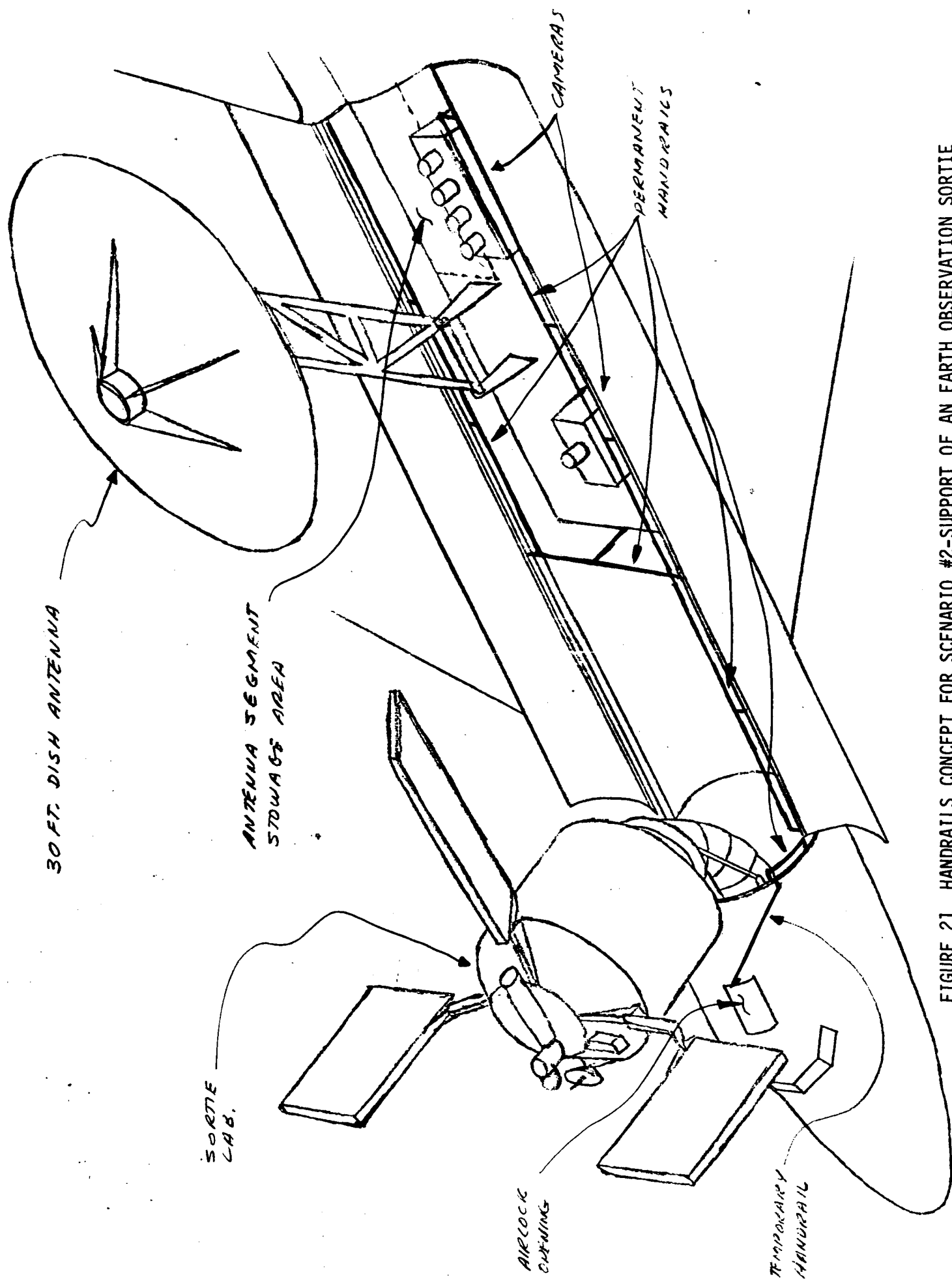


FIGURE 21 HANDRAILS CONCEPT FOR SCENARIO #2-SUPPORT OF AN EARTH OBSERVATION SORTIE

position and the payload bay doors closed. The sortie lab will block access from the orbiter cabin into the payload bay. Access could be gained through one of the rear payload bay doors by placing temporary handrails on the exterior surface between the airlock opening and the door.

The use of electroadhesive devices would require the placement of a conductive surface along the handrail path shown in Figure 21 to be followed to the pallet and over the surface of the pallet.

A MWP would not be applicable in this situation since the worksites are in the same area where the MWP would be stored.

Figure 22 shows a manipulator with an end effector for crew transfer for support of an Earth Observation Sortie. For access into the payload bay with the sortie lab in the stowed position and the payload bay doors closed is gained by opening one of the rear payload bay doors. Handrails would then be required inside the cargo bay, similar to those in Figure 21, for crew translation.

1.1.3.3 Satellite and Tug Retrieval and Deployment Readiness Scenario #3

Figure 23 shows single handrails for this scenario. The permanent handrails are shown placed such that they may be used in both the docked and stowed positions. Some handrails may also be required in the aft end of the payload bay for crewman translation in that area.

The use of electroadhesive devices would require conductive surfaces along the handrail paths shown in Figure 23 plus in the aft end of the payload bay.

Figure 24 shows the use of a MWP for de-orbit readiness. In this scenario the total length of the payload is short enough (≈ 45 ft) to

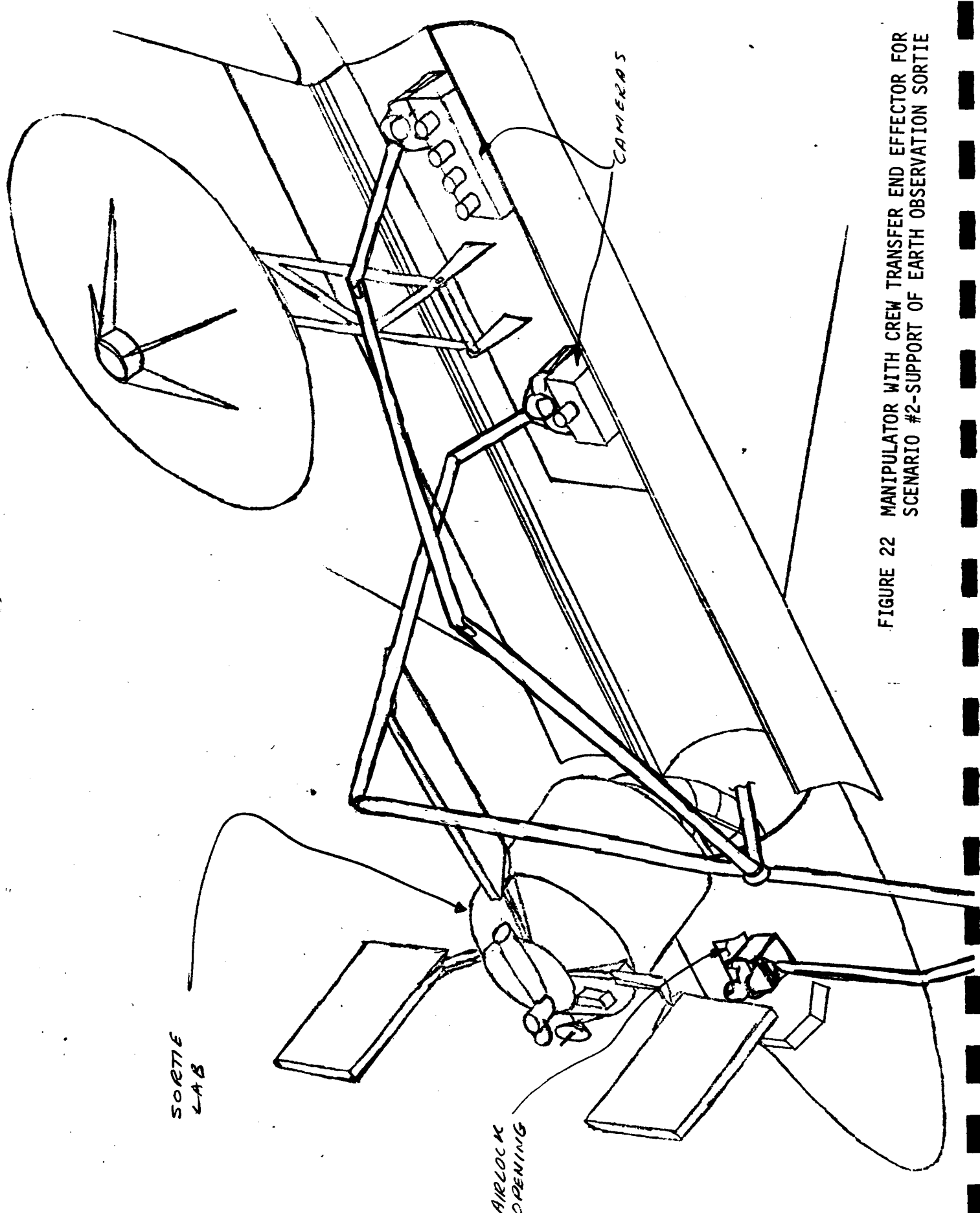


FIGURE 22 MANIPULATOR WITH CREW TRANSFER END EFFECTOR FOR
SCENARIO #2-SUPPORT OF EARTH OBSERVATION SORTIE

SORTIE
LAB

AIRLOCK
OPENING

SYNCHRONOUS EQUATORIAL EARTH
RESOURCES OBSERVATORY (SEEO)

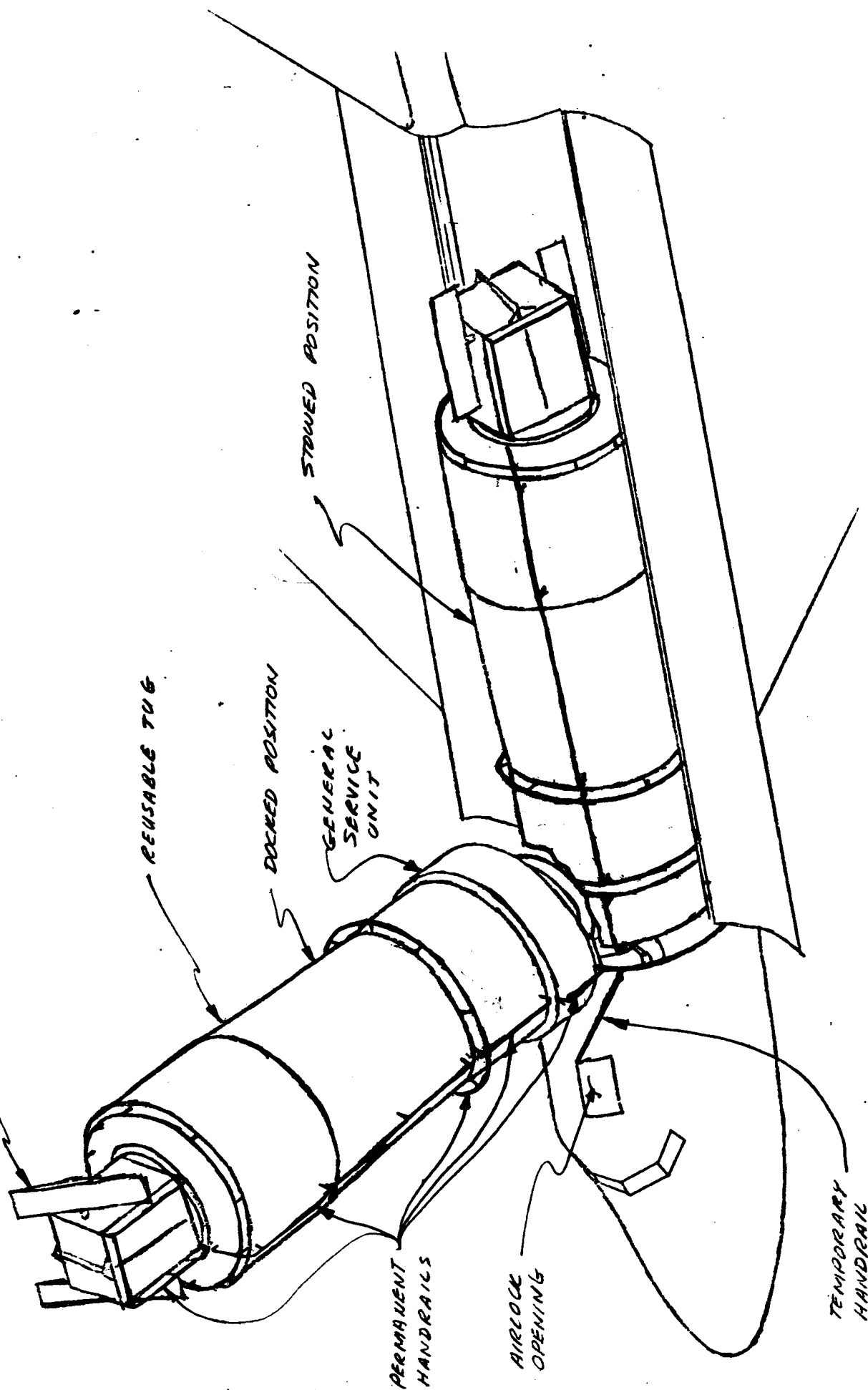


FIGURE 23 HANDRAILS CONCEPT FOR SCENARIO #3-SATELLITE & TUG RETRIEVAL & DEPLOYMENT READINESS

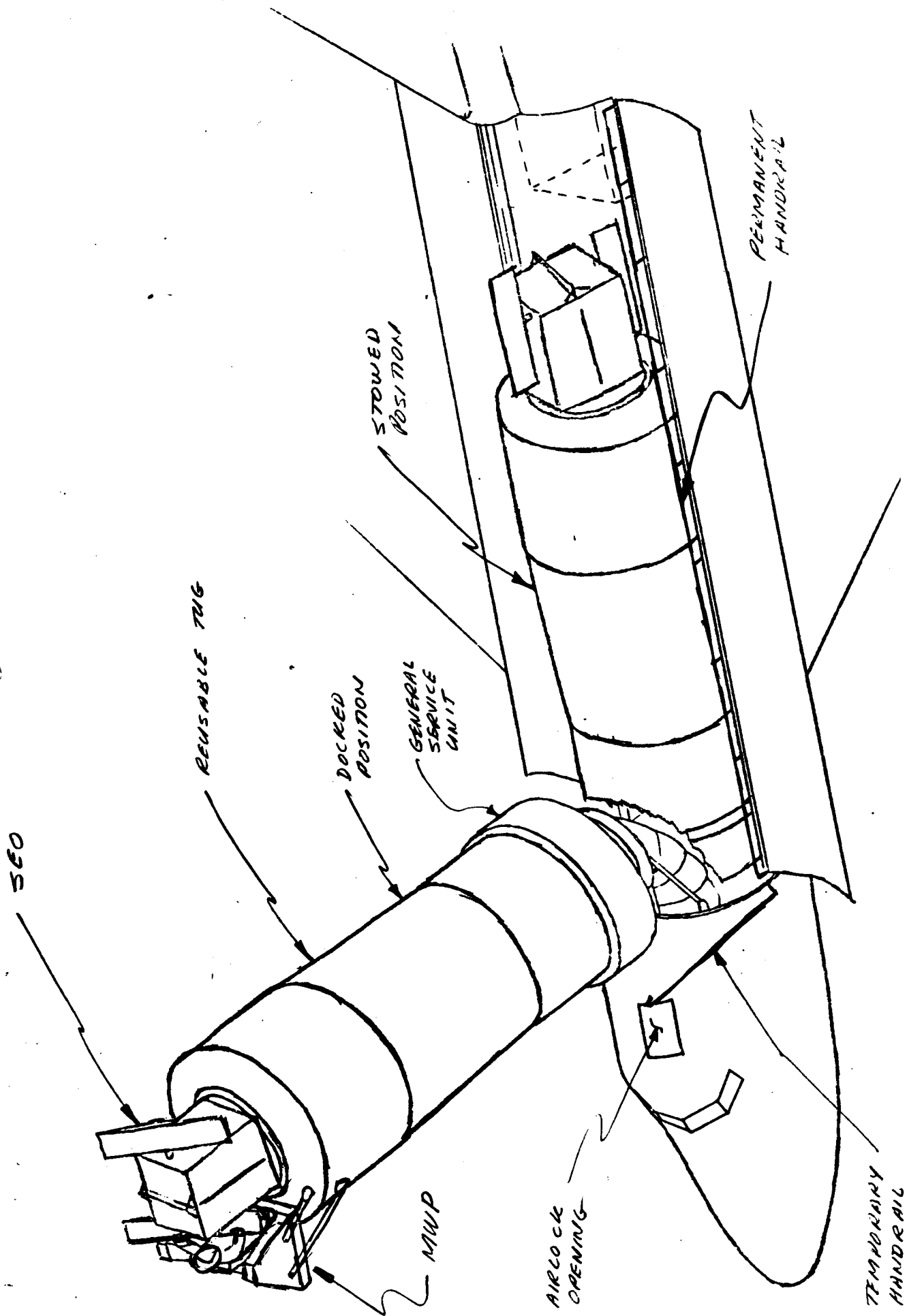


FIGURE 24 MANEUVERING WORK PLATFORM (MWP) FOR SCENARIO #3-SATELLITE AND TUG RETRIEVAL AND DEPLOYMENT READINESS

allow a MWP to be in the payload bay also. Handholds are required for crew translation from the airlock opening to the MWP stowage area.

Figure 25 shows the use of a crew transfer manipulator end effector for this scenario.

1.1.3.4 Inspection and Repair of the Orbiter Vehicle Exterior Scenario #4

Handrails could be provided which could be installed on orbit as required, where required to accomplish the inspection and repair task. Mechanical attachments could be used allowing the handrails to be installed for use and removed when no longer required. Bonded attachment could be used and constructing the hand grip from a suitable low melting point or subliming material would allow the protuberance to burn-off early during reentry heating. The basis for this concept derives from the requirement to prevent the intense local aerodynamic heating which occurs about a protuberance during reentry flight. The local heat shield surface where the grip was located would then be subjected to nominal heating for the majority of the reentry, and experience the magnified (2 to 5X) protuberance heating only until the grip destructs.

Burnoff type handholds were used on the Apollo CM. The configurations, locations, and thermal design analysis are described in Appendix A. It was a design objective that the grips fail early during entry. This objective proved to be difficult to meet for the following reasons:

1. The requirement to survive boost heat soakthrough the CM boost cover.
2. The functional, strength, and interface requirements were not necessarily compatible with the burnoff objective.

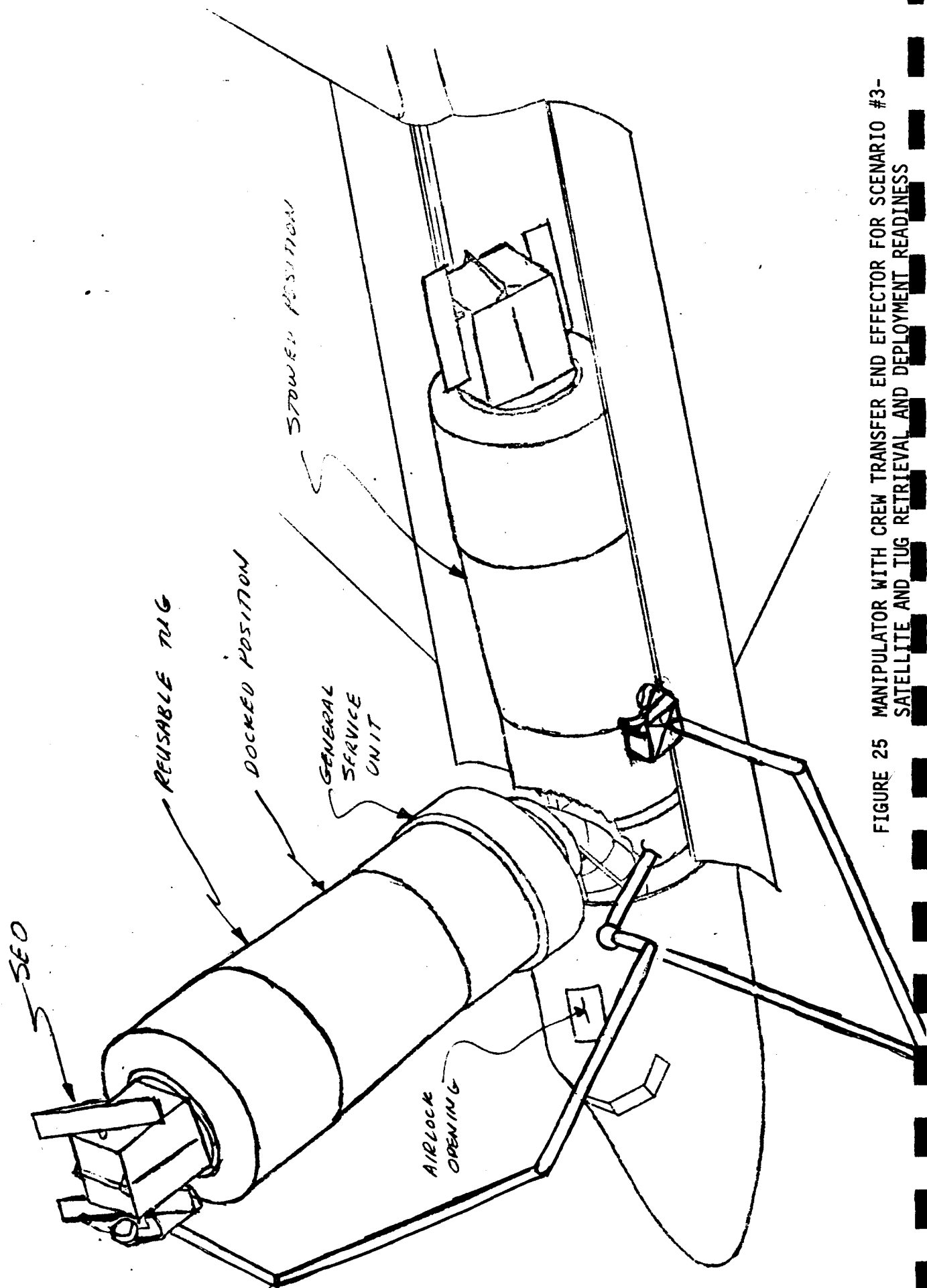


FIGURE 25 MANIPULATOR WITH CREW TRANSFER END EFFECTOR FOR SCENARIO #3-
SATELLITE AND TUG RETRIEVAL AND DEPLOYMENT READINESS

3. The wide envelop of design reentry trajectories.
4. The difficulty in qualification and simulation testing of the designs.

The Apollo CM is recovered after landing and the heat shields and components are visually examined. The results of post-flight examination of the grips is that these components survive, but suffer some degrading and partial melting.

In addition to functional requirements, the shuttle heat shield is required to be reusable without (or minimal) maintenance. The shuttle heat shield uses reusable surface insulation (RSI). Three types of materials are used depending upon the heating zones. On leading or stagnation areas, reinforced carbon carbon (RCC) is required. On windward attached flow areas, ceramic RSI is required. On the leeside, the mildest heating location, elastomeric RSI is specified. Figure 26 shows the material zoning, thickness profile, and temperature distribution during maximum reentry heating or during boost heating which does drive local design areas.

The elastomeric RSI zone includes the cargo bay and aft of the cabin. This material is limited to 650°F and is sized to limit aluminum primary structure temperature to less than 350°F.

Considering the thermal environments over these areas, likely material candidates for handhold grips are nylon, teflon, and similar thermoplastics.

The design concept for disposable (burnoff) handholds is a feasible approach for Shuttle. It appears though that this approach is difficult to apply successfully as evidenced by the Apollo experience. The Shuttle boost phase, in particular, presents a prior thermal environment,

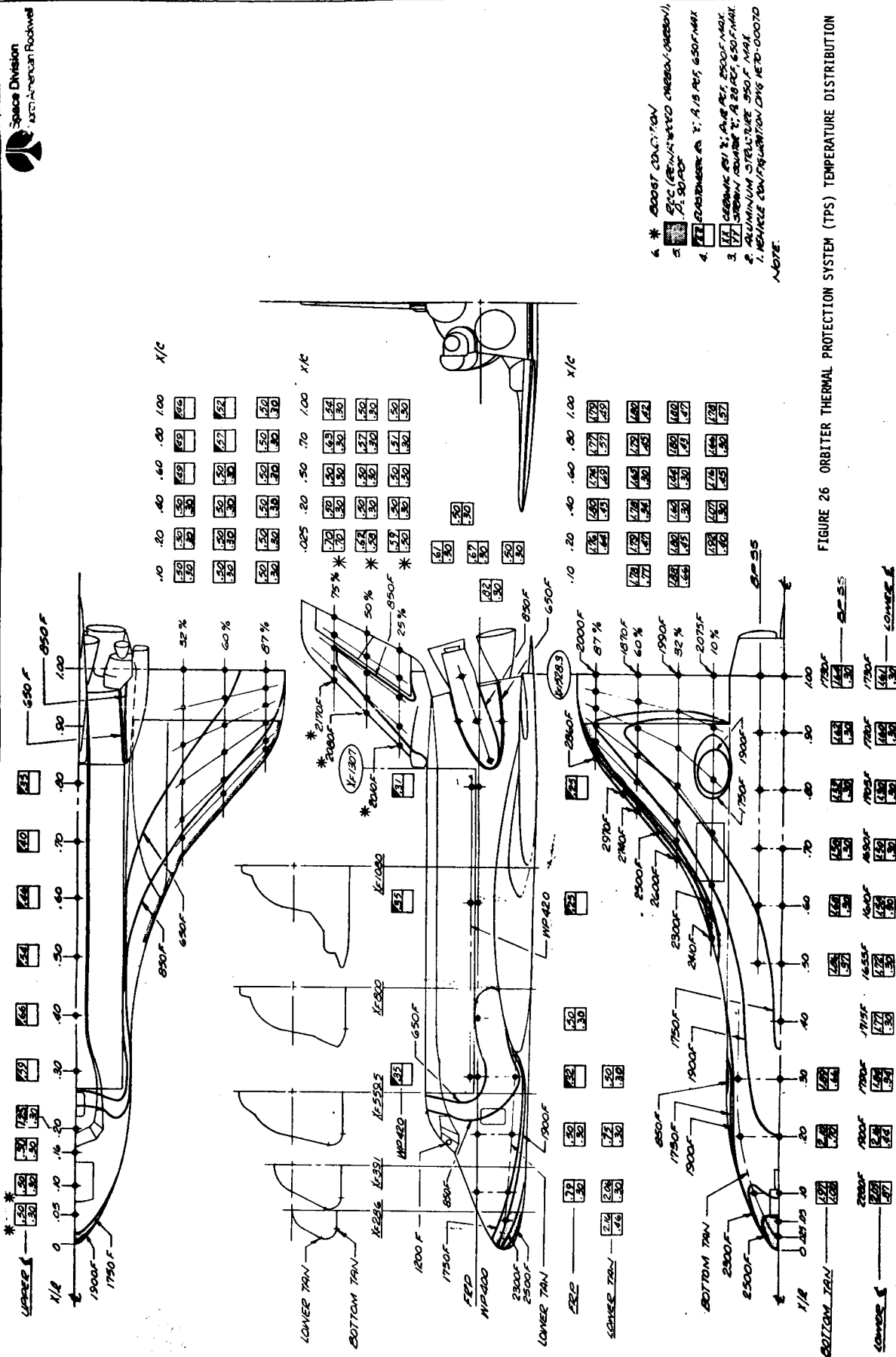


FIGURE 26 ORBITER THERMAL PROTECTION SYSTEM (TPS) TEMPERATURE DISTRIBUTION

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during which the grip must survive, comparable to the reentry phase environment during which the grip should fail. Covers or low profile storage and deployable grips may be considered.

The use of electroadhesive devices would require that conductive surfaces be provided for translation over the entire exterior of the orbiter vehicle.*

A MWP could be used for this scenario. Space would be required in the payload bay for stowing the MWP and handholds would be required for crew translation from the airlock opening to the MWP stowage area. Some method of restraining the MWP at the worksite would be required. A bonded on attachment could be provided which would "burn off" when the orbiter reenters.

Figure 27 shows the manipulator with a crew transfer end effector used to accomplish this scenario. In order to reach all of the orbiter exterior longer arms and an additional joint would be required. Since the payload bay doors must be open in order to utilize the manipulators the exterior of the payload bay doors and the surface of the wings and fuselage covered by the doors cannot be reached using a crew transfer end effector.

1.1.3.5

IVA Maintenance of An X-Ray Astronomy Observatory

Scenario #6

Figure 28 shows single handrails for manual crew translation and cargo transfer for X-Ray Observatory maintenance. The proper placement of the handrails would allow access to the three worksites from the access panel. Temporary or deployable handrails may be required if permanent installation would interfere with the observatory operation.

The use of electroadhesive devices would require the placement of a conductive surface along the paths to be followed to the worksites.

* Latest versions of ceramic RSI coated with silicon carbide may be electroconductive, and should be subjected to feasibility studies with electroadhesors.

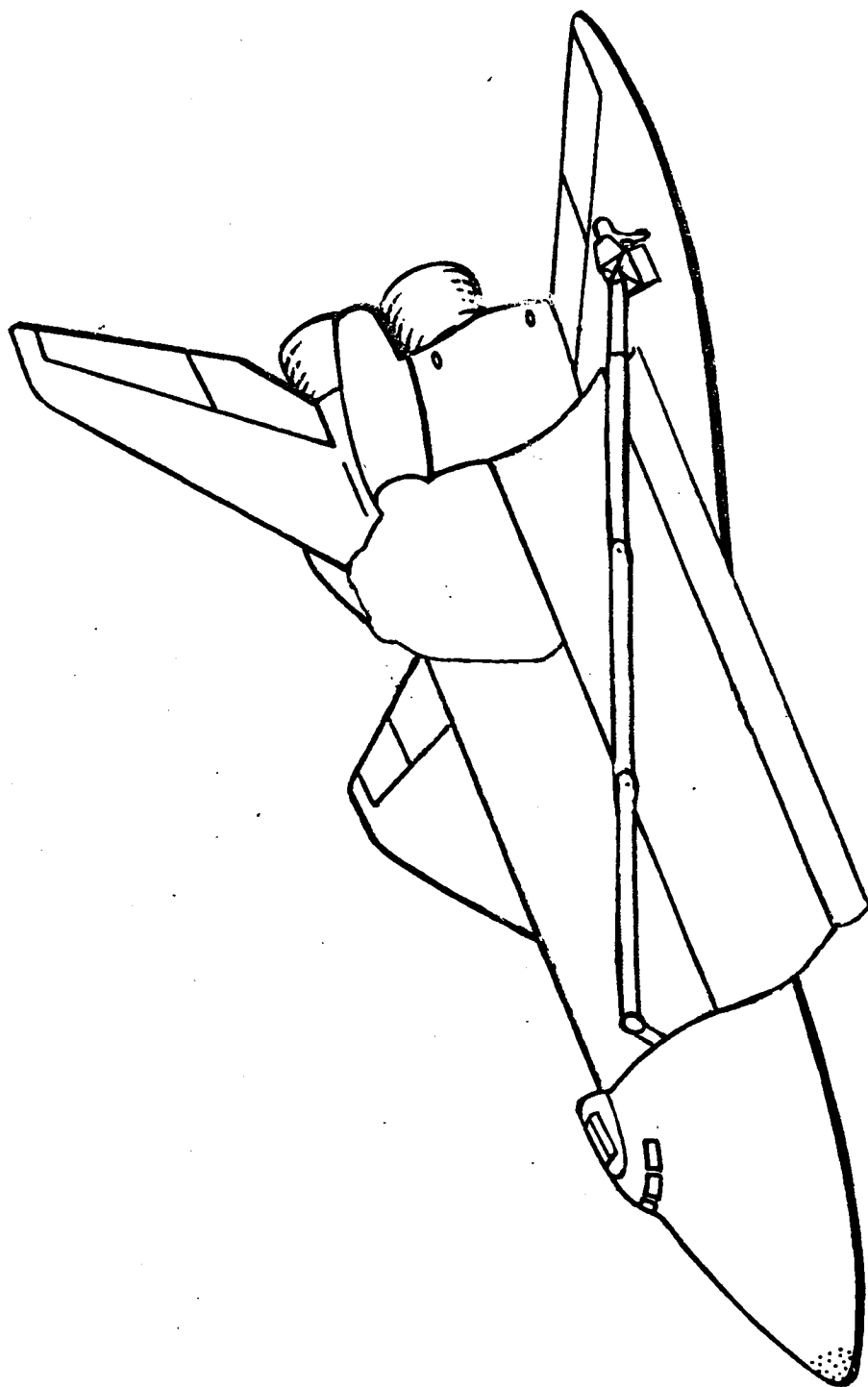


FIGURE 27 MANIPULATOR WITH CREW TRANSFER END EFFECTOR FOR SCENARIO #4 -
INSPECTION AND REPAIR OF THE ORBITER VEHICLE EXTERIOR

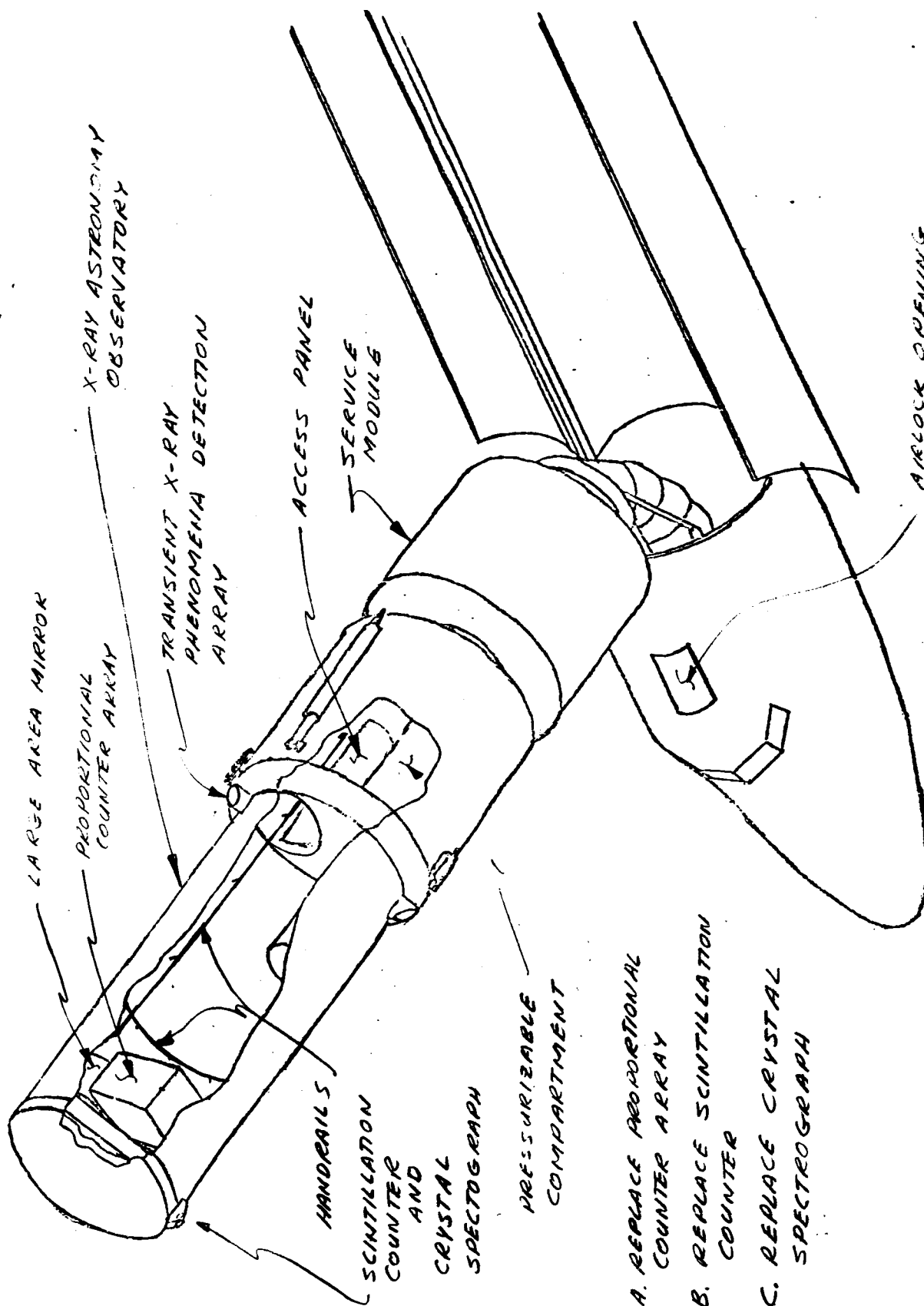


FIGURE 28 HANDRAILS CONCEPT FOR SCENARIO #6-IVA MAINTENANCE OF AN X-RAY ASTRONOMY OBSERVATORY

MWP and the manipulator with an end effector for crew transfer would not be applicable for this scenario.

1.1.4 Translational Devices Evaluation and Recommendations

Advantages and disadvantages of the crew translational and cargo transfer concepts are listed, the concepts are then compared and evaluated and recommendations are made relative to the use of translational devices on the Shuttle Program.

1.1.4.1 Advantages and Disadvantages

1.1.4.1.1 Crew Translational Devices

Single or Dual Handrails

Advantages:

Design exists for permanent handrails.

Disadvantages

- o Large impact on payload hardware and hardware design cost to provide handrail path to all planned EVA and IVA worksites.*

- o Lighting required along the handrail path will impact payload hardware and hardware design for installation.

- o Lighting will use orbiter electrical power.

- o Portable handrails would be required for unscheduled EVA/IVA.*

- o Moderate to large crewman effort required to utilize.

Electroadhesive Device

Advantages

- o Very light weight. Only an additional conductive layer required along translation path if a conductive layer does not exist on the

* Impact greater for dual handrails.

payloads and orbiter.

- o Versatile - can use for planned or unscheduled EVA or IVA
- o Handy to use

Disadvantages

- o Must be developed and qualified
- o Requires orbiter electrical power
- o EMI interferences
- o Requires positive crew retention such as a tether

Maneuvering Work Platform

Advantages

- o Capability to translate far enough away from the orbiter vehicle to work on satellites without fear of contamination from the orbiter
- o Capability to carry tools, spare parts, checkout equipment, crewman restraint, worksite provisions, and life support equipment necessary to accomplish on-orbit satellite repair
- o Minimum payload impact, need only provide a place for grapple to attach for workstation rigidity

Disadvantages

- o Heavy
- o Large volume
- o Servicing required from orbiter if more than one EVA

is performed

- o Development costs

Crew Transfer End Effector

Advantages

- o Versatile - provides crew translation to both planned and unscheduled EVA worksites

Disadvantages

- o Uses orbiter electrical power
- o Moderate payload impact. Requires crewman restraint and worksite provisions (lighting and equipment retention) at each planned worksite
- o Development Cost
- o Weight and volume
- o Contingency return method required
- o Capability limited by limited manipulator arm reach

Work Platform End Effector

Advantages

- o Versatile - provides crew translation to both planned and unscheduled EVA worksites
- o Minimum payload impact, need only provide a place for tying the work platform to the worksite for rigidity
- o Capability to carry tools, spare parts, checkout equipment, crewman restraint, worksite provisions and life support equipment necessary to accomplish EVA tasks.

Disadvantages

- o Uses orbiter electrical power
- o Development costs
- o Weight and volume
- o Contingency return method required
- o Capability limited by limited manipulator arm reach

1.1.4.1.2

Cargo Transfer Devices

Dual Handrails

Advantages

- o Design exists
- o Only required if cargo package moment of inertia greater than 15 slug-ft² or if weight greater than 300 pounds

- o Low hardware cost

Disadvantages

- o Large crewman effort required to control and move cargo
- o Integration into the design of each payload is required

Cargo Transfer End Effector

Advantages

- o No effort required of EVA/IVA crewman to move cargo
- o EVA/IVA crewman translation rate is high
- o Existing or extension of capability of manipulator being developed for orbiter

Disadvantages

- o Development cost required to show capability or extend capability of manipulator being developed for orbiter
- o Orbiter electrical power required
- o Manipulator operator required
- o Manipulator arm length limited

Stem Powered Transfer Device

Advantages

- o Design exists for Skylab

Disadvantages

- o Separate mounting required at worksite
- o EVA/IVA crewman required at each end, a sender and a

receiver

- o Orbiter electrical power required
- o "Line-of-Sight" transfer path required

Body Tethers

Advantages

- o Designs exist

Disadvantages

- o Tethered cargo interfere with crewman translation
- o Creates high point loads in space suit

1.1.4.2

Comparisons and Evaluations

Handrails are a proven method of crew translation, with the cargo being transferred manually while tethered to the crew. Dual handrails would extend the crew's cargo transfer capability to include packages with large moments of inertia. For EVA and IVA involving a single crewman these devices stand out as the means of manual crew and cargo transfer until such time as electroadhesive devices are developed. When electroadhesive devices are developed the handrails could be eliminated and conductive coating paths provided, resulting in payload weight reductions.

A work platform end effector stands out as the one device offering the most advantages for use as powered crew and cargo transfer, by combining all mobility aids. The use of crew transfer end effector would reduce impact on the payloads, but leave the impact of providing worksites.

Either end effector will, however, only provide for EVA, within the limited reach of the manipulator arms.

A maneuvering work platform offers the same advantages as a work platform end effector plus the capability to provide for all EVA, including remote, on-orbit satellite repair. The development cost, however, would be high.

There will exist on the orbiter vehicle two manipulator arms with a terminal device (end effector) to handle packages with these characteristics:

	<u>Size</u>	<u>Weight</u>	<u>Moment of Inertia</u>
Smallest	2' dia x 3'	700 lb	11 slug-ft ²
Largest	15' dia x 60'	60,860 lb	668,000 slug-ft ²

The same terminal devices used to handle these packages may also be capable of handling smaller packages without change. If the terminal devices could handle smaller packages of cargo, down to a size which would fit into a pocket on a space suit, there would be no need for additional cargo transfer devices, within the reach of the manipulator arms.

Stem powered cargo transfer devices would require two men EVA/IVA.

1.1.4.3 Translational Devices Recommendations

It is recommended that:

1. A work platform end effector be developed plus devices which will extend the reach and position capability of the existing manipulator arms to include distances of 80 feet as a minimum.

2. Handrails be used for EVA crew and cargo transfer beyond the limits of the manipulator arms and for IVA, with cargo packages tethered to the space suit.

3. Dual handrails plus tethers be used for cargo transfer beyond the limits of the manipulator arms and for IVA, for packages with a moment of inertia over 15 slug-ft² and/or a weight of over 300 pounds.

4. The manipulator development program be expanded to include a demonstration of the capability to handle cargo packages as small as 125 in³ and 1 pound.

5. Pockets be provided on the EVA/IVA space suit to handle cargo packages under 125 in³ and 4 pounds.

6. The electroadhesive devices be pursued further as possible replacement of the handrails to gain versatility and reduce payload weight.

7. A maneuvering work platform be developed if contamination from orbiter effluents is shown to be a problem during on-orbit repair.

1.2 Restraint Devices

Crewman worksite restraint devices are discussed, evaluated and recommendations made relative to their use on the shuttle program. Three types of restraint devices are discussed, foot restraints, handholds and waist restraints.

1.2.1 Foot Restraints

Foot restraints were utilized on Gemini and Apollo. The experience gained from these programs led to the foot restraint devices, shown in Figure 29, to be used at the three prepared worksites on Skylab, Ref. 8. The toe of the crewman's boots are inserted under each bar and the heel rotated to engage the foot restraints.

Astrogrid shoe restraint will be used in the Skylab workshop (Ref. 11). The restraint system shown in Figure 30 consists of a floor grid

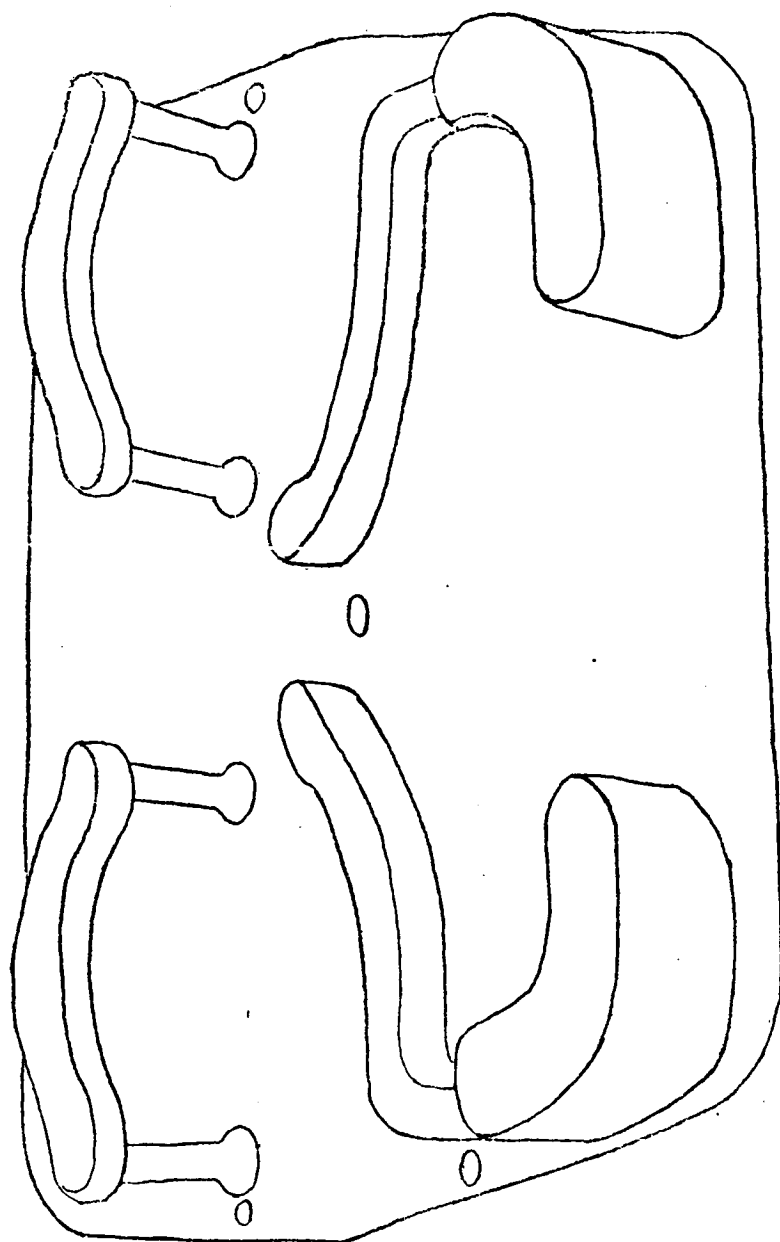


FIGURE 29 SKYLAB FOOT RESTRAINT (From Ref. 8)

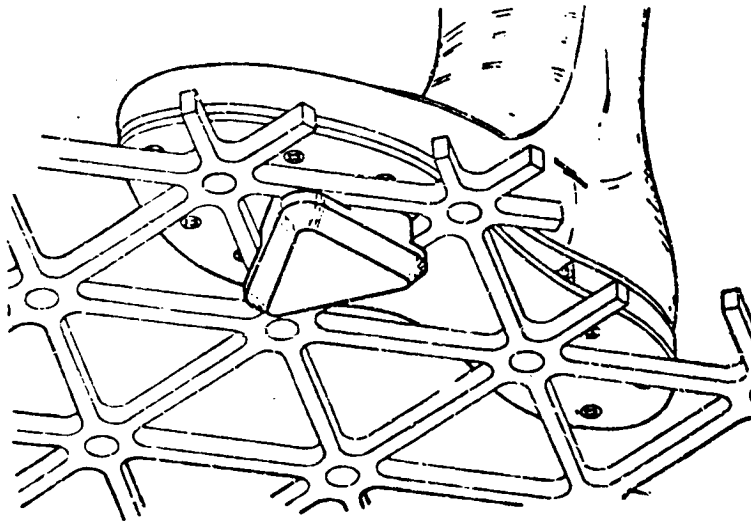


FIGURE 30 SKYLAB ASTROGRID SHOE RESTRAINT (From Ref. 11)

surface of triangular holes in a hexagonal array. Shoes are provided with interfacing, triangular shapes or cams, which are mounted off the mid-sole of the shoe. The system acts as both a restraint and a mobility device. The crewman inserts the cam of the shoe into a triangular hole in the floor grating. By then twisting the shoe a given amount, the shoe becomes securely fastened to the grating.

The electroadhesive devices discussed in 1.1.1.3.2 could be utilized as worksite foot restraint in addition to being used as mobility aids.

1.2.2 Handholds

Gemini - Three fixed handholds were provided on the back of the docking cone on the Gemini XI Agena Target Vehicle to provide restraint during the spacecraft/Agena Target Vehicle tether attachment. Two similar handholds (Figure 31) were provided on the back of the docking cone on the Gemini XII Agena Target Vehicle. The handholds were 6.5 inches in length and 1 inch in diameter, with a 1.5-inch clearance from the surface. These handholds were coated with a resilient friction material which was helpful. The handholds proved very useful in flight; however, the pilot favored a metal handhold of rectangular cross section rather than the coated cylinder.

Flexible Velcro-backed portable handholds were evaluated as restraints and as maneuvering aids during the Gemini IX-A mission. Two fabric-backed nylon Velcro-pile pads were carried in the spacecraft. The pilot attached the pads to his gloves with an elastic strap wrapped around the palms of his hands. The significant results were:

(a) The elastic attachment was inadequate, and one of the handholds was pulled off the pilot's hand.

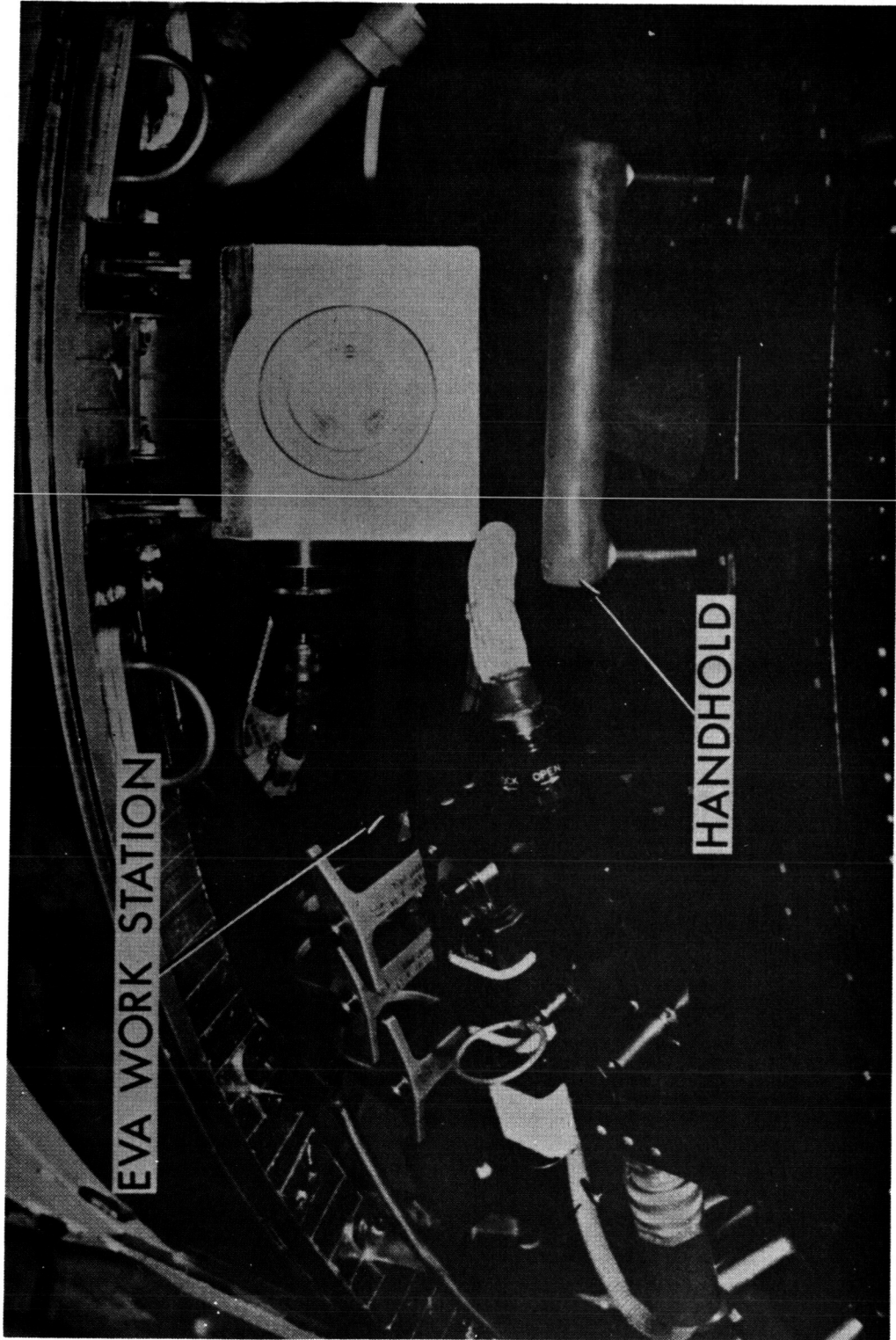


FIGURE 31 Gemini XII Agena Target Vehicle Work Station

(b) The contact forces were insufficient to accommodate controlled maneuvering or body attitude, but were adequate for holding a stationary position.

(c) The unprotected nylon Velcro hook on the spacecraft nose was damaged by launch heating.

For Gemini XII, four trowel-shaped, rigid, Velcro-backed, portable handholds (Figure 32) were installed in the EVA work areas. The handholds were 6.5 inches in length and 1 inch in diameter, and they were coated with resilient material. Each handhold also had a tether attachment ring (1.5 inches in diameter) at one end of the handle.

Detailed evaluation of the rigid handholds was not included in the flight plan for the Gemini XII EVA because of the limited time available for EVA. Analyses and simulations indicated a number of limitations to the usefulness of the devices. The consensus was that fixed handholds were superior to portable devices and that the portable handholds should be used only when fixed handrails or handholds could not be provided.

Pip-pin handhold/tether attachment devices (Figure 33) were used on Gemini XII. The T-shaped pip-pins were 3 inches wide to facilitate their use as handholds; a loop with an inside diameter of 1.75 inches was installed for tether attachment. The crewman used these devices as handholds during changes in body position and as waist tether attachment points during some of the work tasks on the Agena target vehicle.

Pip-pin antirotation devices were installed over some of the pip-pin attachment holes.

The T-shaped pip-pins were a convenient shape and size for hand gripping. When the rotational freedom of the devices was removed, they

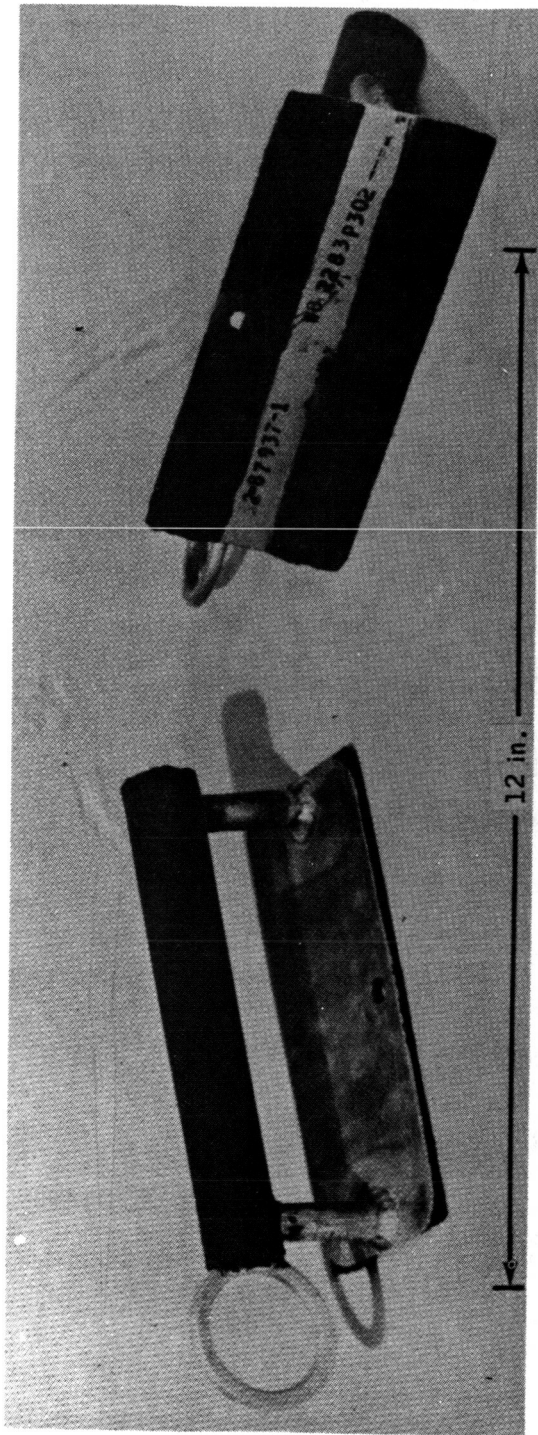


FIGURE 32 Rigid Velcro-Backed Portable Handholds

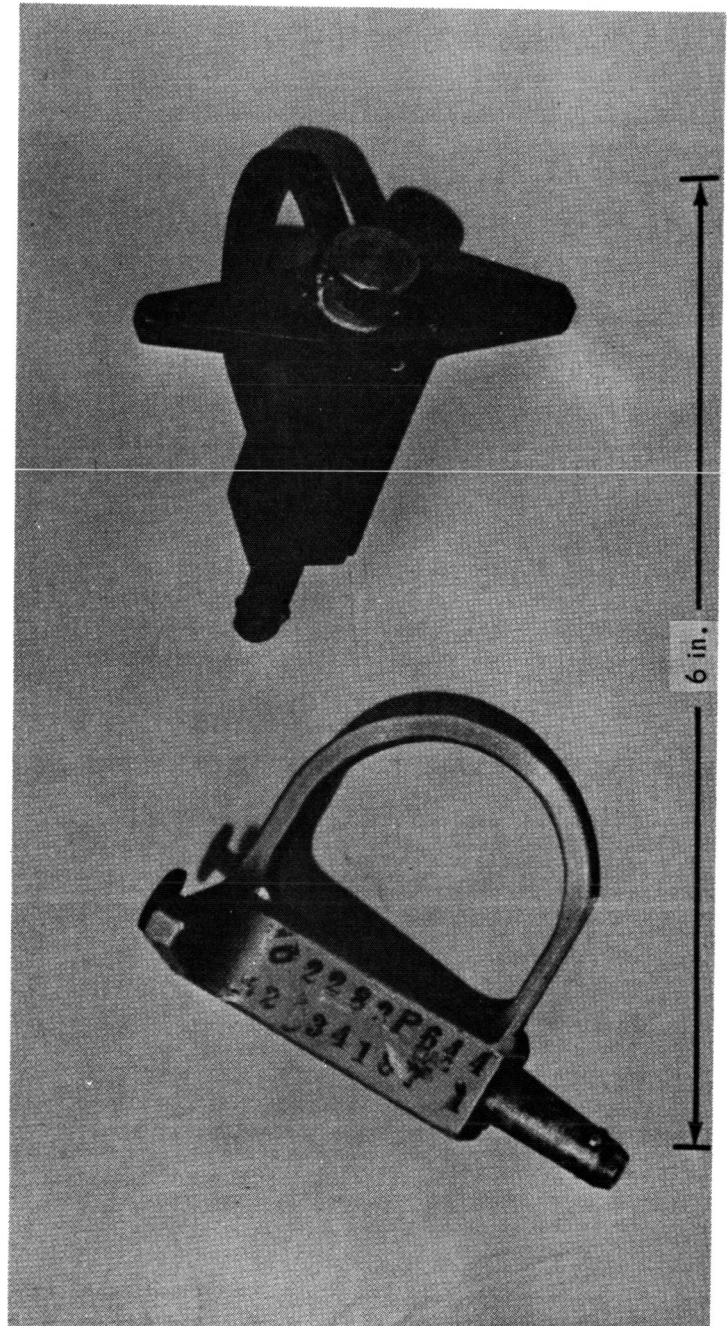


FIGURE 33 Pip-Pin Handhold/Tether Attachment Devices

were excellent handholds, helped to control body attitude, and were useful as waist tether attachment points because waist tether attachment was simplified. However, with the antirotation devices in place, the pip-pins had to be in one of eight specific orientations, and this requirement complicated the installation. Therefore, if pip-pin devices are used, antirotation devices are desirable; but the requirement for such precise alignment is undesirable.

U-bolt handhold/tether attachment devices were installed in the EVA work areas on Gemini XII (Figures 31 and 34). The devices were bare metal, 0.250 inch in cross-sectional diameter, and 1.5 and 2 inches in inside diameter. These dimensions provided ease of hook attachment and a convenient handhold. The crewmen used two of the U-bolts as waist tether attachment points during the work without foot restraints. The crewman found the U-bolts on the target vehicle useful for waist tether attachment and as handholds during work tasks and position changes (Ref. 2).

Apollo - Some of the handrails discussed in 1.1.1.2 were also used as worksite handholds.

Skylab - Some of the handrails discussed in 1.1.1.3 were also used as worksite handholds.

1.2.3 Waist Restraint

The Gemini XII waist tethers (Figure 35) were made of stiff nylon webbing with a length adjustment buckle and a large hook for attachment to the various tether attachment rings. The waist tethers were looped around the crewman's parachute harness and were fastened together with two large snaps. A large fabric tab was provided to facilitate opening the snaps in a pressurized suit. A D-shaped ring was provided for making length adjustments, and it was used several times by the pilot. The adjustment buckle,

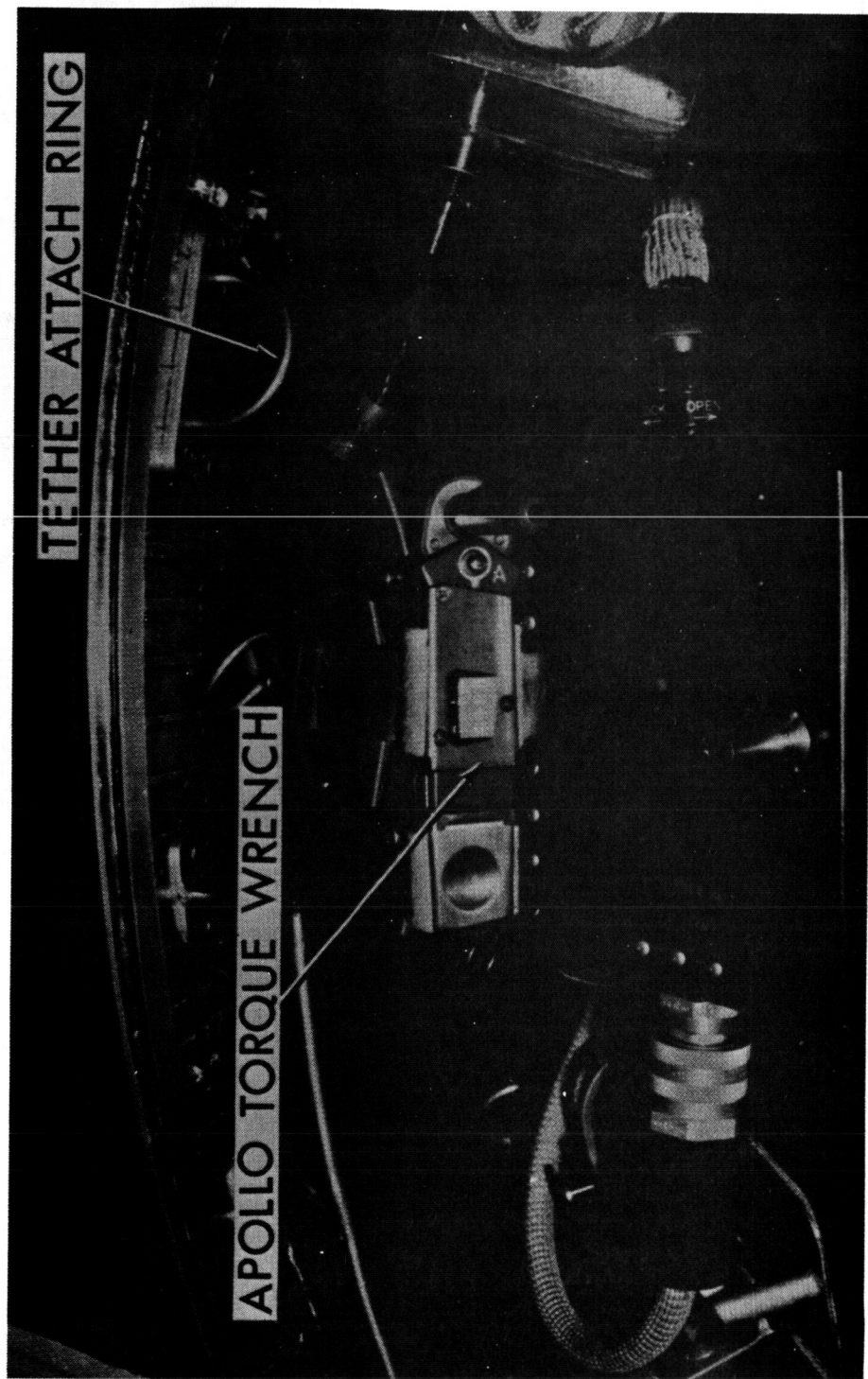


FIGURE 34 EVA Provision on Gemini XII Agena Target Vehicle Docking Cone

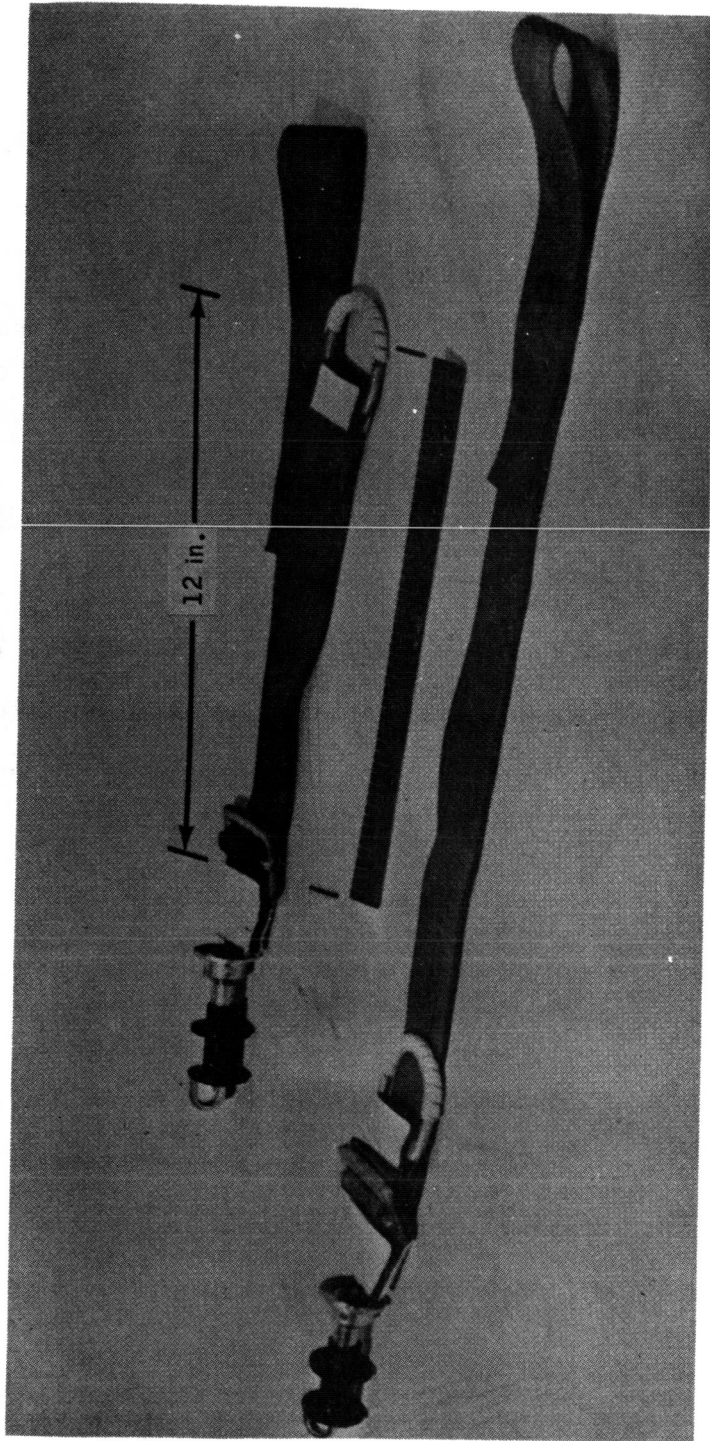


FIGURE 35 Gemini Waist Tethers

a conventional single-loop buckle, allowed length adjustment approximately from 21 to 32 inches. Large flange hooks were used on the waist tethers.

The locations of the tether attachments on the parachute harness at points slightly below waist level were optimum. The crewman used a variety of devices for attaching the tethers in the spacecraft adapter section and on the target vehicle. A pair of handholds, or other restraint, near each pair of tether attachment points is desirable. It was determined that the waist tether attachment points should be as far apart as possible (42 to 48 inches), consistent with the suited crewman's reach, and located at the crewman's sides rather than directly in front of him. Adjustments in length are not required for body tethers.

The crewman was able to install and tighten a bolt to about 250 inch-pounds, using a conventional dial-indicator torque wrench. The wrench handle was 9 inches long; hence the force applied was approximately 28 pounds.

The waist tethers provided the required restraint for the crewman to attach the spacecraft/target vehicle tether, to activate an experiment package, and to disconnect and connect a fluid connector and an electrical connector. The crewman used the 5-inch Apollo torque wrench and was able to exert greater than 100 inch-pounds of torque. Body tethers provided a greater capability for applying torque, minimized the effort required in controlling body position, and eliminated the possibility of drifting away if a tool slipped.

Body tethers eliminated the constant problem of drifting while working or while resting. The waist tethers permitted the crewman to relax during the designated rest periods or at any other time. (Ref. 2)

1.2.4 Restraint Devices Evaluation

Skylab mission simulations have shown that the three foot restraints give adequate body restraint for the accomplishment of the required tasks. No waist restraints are required in addition to the foot restraints.

All the EVA's and IVA's defined in the scenarios indicate that one body position at each worksite will be adequate, therefore there is no requirement for the use of astrogrid for worksite restraint.

It was shown on Gemini and Apollo that handholds are required at workstations to aid in body positioning. Whether they are permanent or portable handholds depends upon the particular application. Plug in portable handholds are available, however the use of electroadhesive handholds would reduce the weight of the payload interface, since a conductive layer is in place of a rigid fitting. Also versatility in the positioning of the handhold would be improved by the use of electroadhesive handholds.

1.2.5 Restraint Devices Recommendations

It is recommended that:

1. Skylab type foot restraints be used at all planned worksites.
2. Waist tethers be utilized as safety tethers only, not body restraint.
3. Handholds be provided at each worksite as required.
4. Use handrails as handholds where possible.
5. Handholds be permanent where possible, and plug in otherwise.
6. Electroadhesive handholds be developed to reduce the payload interface weight.

1.3 Worksite Provisions

The worksite provisions include lighting and equipment retention devices provided at the worksites to aid the crewman in the accomplishment of his tasks. These provisions are discussed and recommendations made relative to their use on the Shuttle Program. Before discussing the worksite provisions a definition of a worksite is given for convenience.

1.3.1 Worksite Definition

A worksite is defined as a location where an EVA astronaut remains stationary for some period of time to perform specific operations. The worksite is composed of, or supported by, a group of interdependent systems. In developing a worksite, hardware must be integrated with the operational procedures to support a particular task. There are two general classes of worksites; (1) prepared and (2) unprepared. A prepared worksite is one in which the site location and the EVA operations to be performed at the site are established during equipment design. The site contains all lighting aids, restraint systems, and control and displays required by the crewman to perform worksite activities. Unprepared sites are locations where an astronaut terminates translation activities to perform a unscheduled or contingency EVA task. The location of the unprepared site is determined immediately prior to or during EVA. Examples of prepared and unprepared worksites are presented in Table XI. Prepared and unprepared worksite development beginning with the Gemini Program and continuing through the Skylab Program, has generated a set of worksite characteristics which should be considered when designing a prepared worksite. These characteristics are presented in Table XII.

TABLE XI SUMMARY OF PREPARED AND UNPREPARED WORKSITES

MISSION	PREPARED WORKSITES		UNPREPARED WORKSITES	
	WORKSITE	ACTIVITIES	ACTIVITIES	
<u>Gemini</u> IV IX-A X	Gemini Hatch Gemini Hatch Adapter Section Gemini Hatch	16mm camera installation. Umbilical guard installation Handrail deployment. S-012 micrometeoroid package retrieval Astronaut Maneuvering Unit (AMU) donning S-012 retrieval	Velcro hand-pad evaluation N ₂ line disconnect. S-010 Micrometeoroid package retrieval at GATV. T-017 micrometeoroid experiment intallied at GATV Tether attachment	
	XI Adapter	UV Stellar Photography Foot restraint evaluation		
	XII Gemini Hatch Target Docking Adapter Adapter	UV stellar photography. Synoptic terrain photography. Handrail deployment Tether attachment. Evaluation of work tasks. Retrieval of S-010 Evaluation of work tasks		
		Photography Photography, sample retrieval Retrieve film from 24" panoramic and 3" mapping cameras. Inspect SIM Bay Assist film retrieval, photography, manage umbilical		
<u>Apollo</u> 9 15 16 17	Command Service Module Hatch Lunar Module Hatch SIM Bay Command Service Module Hatch SIM Bay Command Service Module Hatch SIM Bay Command Service Module Hatch			
<u>SkyLab</u>	VF: FAS Workstation VC: Center Workstation VS: Sun End Workstation VT: Transfer Workstation	Film handling and loading, photography, umbilical management, sample retrieval Film retrieval/replacement, umbilical management, photography Film retrieval/replacement, umbilical management, photography Film handling and loading, photography, umbilical management		

(from Ref. 1)

TABLE XII WORKSITE CHARACTERISTICS

STABILIZATION	SITE LOCATION	ASTRONAUT/WORKSITE INTERFACE	
<ul style="list-style-type: none">• Type of Stabilization<ul style="list-style-type: none">Restraint<ul style="list-style-type: none">Handhold/footholdBoth restraints and hand/footholdCagePortable or fixedRestraint Location<ul style="list-style-type: none">WaistFootOther body attachment (chest, knee, etc.)Restraint Type<ul style="list-style-type: none">RigidFlexibleRigidizedRetractable - spring loadedHandhold/Foothold Characteristics<ul style="list-style-type: none">LengthHand/foot clearanceLocationRelation to restraintsRestraint Fastener<ul style="list-style-type: none">Quick disconnectPositive feedback of activationRestraint Adjustments<ul style="list-style-type: none">Disconnect/connectTighten/loosenSafety Considerations<ul style="list-style-type: none">Backup tetherRestraints - footholds don't themselves become hazards	<ul style="list-style-type: none">• Type of Location<ul style="list-style-type: none">Whole body in free spaceBody partially in free space - partially in confined spaceWithin unpressurized vehicleTransportable site - as an end of septuator or portable• Relationship to Vehicle<ul style="list-style-type: none">Immediately adjacent to vehicle structuresRemoved from vehicleLine of site or hidden	<ul style="list-style-type: none">• Type of Site<ul style="list-style-type: none">UnconfinedSemi-confinedConfinedLimbs<ul style="list-style-type: none">Whole body<ul style="list-style-type: none">- body clearances- Presence of protuberances• Astronaut Orientation<ul style="list-style-type: none">Body axis parallel to main axis of siteBody axis perpendicular to main axis of siteBody axis off-set from main axis of site	
	SITE ENTRY		
	<ul style="list-style-type: none">• Clearance of Entry<ul style="list-style-type: none">Whole bodyLimbEncumbered - unencumbered• Provisions for Emergency Escape• Safety Hazards Around Entry<ul style="list-style-type: none">ProtuberancesMoving partsUnstable structuresSensitive areas• Visibility of Entry<ul style="list-style-type: none">Color coding of translation aids - handholds, feet restraintsLighting of entire entry wayLighting of worksite within entry• Body Orientation to Entry-Way at Entry<ul style="list-style-type: none">Always head first or frontalSideways entry is acceptable if entry-way and worksite are in the field of view during actual entry• Umbilical Dynamics	<th>MOBILITY</th>	MOBILITY
		<ul style="list-style-type: none">• Motions Required in Worksite<ul style="list-style-type: none">Whole body<ul style="list-style-type: none">RotationalTranslational<ul style="list-style-type: none">- lateral- front-back- up-down- twistingLimbs<ul style="list-style-type: none">Direction of motionRange of motion• Extent of Motion• Frequency of Motions	
EQUIPMENT MOUNTING		CONTROL/DISPLAY	
<ul style="list-style-type: none">• Umbilical Secure• Temporary Storage of Equipment<ul style="list-style-type: none">ToolsSamplesData recording equipment		<ul style="list-style-type: none">• Nominal Operational<ul style="list-style-type: none">LocationSizeTypeOperating characteristicsNumberIlluminationLabellingOrientationRelation of controls to displays• Contingency Operation<ul style="list-style-type: none">AlarmsMalfunction detectionFault isolationCheckout	
FORCE	LIGHTING		
<ul style="list-style-type: none">• Type of Force<ul style="list-style-type: none">SustainedImpulse• Direction of Force<ul style="list-style-type: none">Up/downLateralFore/aftRational• Magnitude of Force• Counter-forces	<ul style="list-style-type: none">• Type<ul style="list-style-type: none">Body mounted<ul style="list-style-type: none">WristHelmetChestHandheldRemovableFixed• Number of Lights• Location of Lights• Field of View• Brightness• Avoidance of Glare• Color• Adjustments<ul style="list-style-type: none">DirectionBrightnessField of view sizeNumber of lightsLocation• Power Requirements	<th>SITE OCCUPANCY</th>	SITE OCCUPANCY
		<ul style="list-style-type: none">• Duration• Frequency - number of times during EVA and during one mission• Number of similar sites	
SITE ACTIVATION			
<ul style="list-style-type: none">• Type of Activation<ul style="list-style-type: none">RemoteLocal - pre-entryLocal - post-entry• Operations<ul style="list-style-type: none">Activation of light sourcesConfiguration of structuresSelection of operational modesDecision to enter site			

1.3.2 Lighting

Reference 14 establishes the requirements for EVA/IVA lighting.

On Skylab, lighting will illuminate the EVA astronaut routes to each workstation with a minimum of 2.0 ft. lamberts. Workstations will be illuminated with 5.0 ft. lamberts level, minimum. The lighting is accomplished by permanently installing as many of one type light assembly as is required to maintain the proper light level. Each light assembly contains a 18.75 watt incandescent lamp (Ref. 8).

Portable lighting assemblies could be provided for unscheduled EVA/IVA. These assemblies would provide the same level of illumination as the permanent Skylab lighting above.

1.3.3 Equipment Retention

An EVA or IVA crewman will need several pieces of equipment at a worksite with him in order to accomplish his assigned tasks. If he is to be efficient in the accomplishment of his tasks this equipment must be attached to something at the worksite so that it will not float away and the crewman can use both hands in accomplishing his tasks. Several methods of retention could be used; solid mounting (as on Skylab), tethers, and pockets on the space suit. All of these methods have been used on Gemini and Apollo with success.

Worksite equipment which must be retained includes tools, spare parts and parts removed for replacement.

The "Astronaut Tool Kit" to be used on the Skylab Program, Reference 13, was designed for IVA use, with 90 percent of the maintenance tasks performed in a shirtsleeve mode, and 10 percent IVA in a pressurized space suit.

A large part of the equipment in the kit is usable for EVA also. Figure 36 shows the tool kit cabinet and Figure 37 shows the tool carrier from Reference 13.

The tool kit in Figure 36 is representative of an item of equipment which may be required to be retained at a worksite. The tool carrier in Figure 37 is representative of a method which could be used to retain selected tools at the worksite.

This tool kit, being developed for Skylab, does not consider planned or unscheduled EVA's to retrieve satellites which have no provisions for retracting deployed antennas, sensors, etc. These deployed devices would be manually retracted or removed by EVA in order to get the satellite into the payload bay and stowed. One method of removing these devices would be to cut them off using bolt cutters or hack saws. The saw device may need to be powered, requiring either a self contained electrical power source or access to orbiter electrical power.

Additional tools may be required for use where an unscheduled EVA is required because of a manipulator failure. Adapters may be required to allow the EVA crewman to grasp where the manipulator end effector would attach.

Retention will be required for these cutters and adapters at the worksites where they are to be used, in addition to the tools and for kit mentioned above.

Representative spare parts and parts removed for replacement are presented in Reference 15 and summarized in Table XIII.

1.3.4

Worksite Provisions Recommendations

It is recommended that:

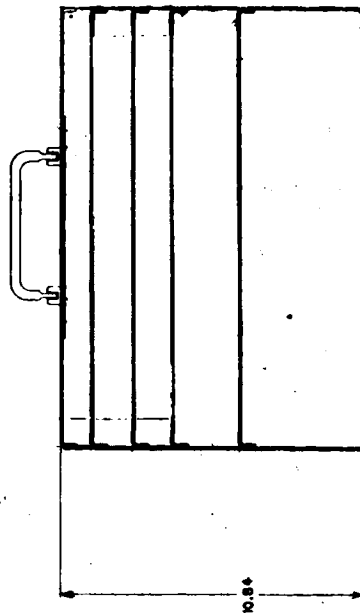
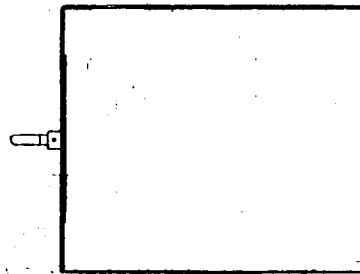
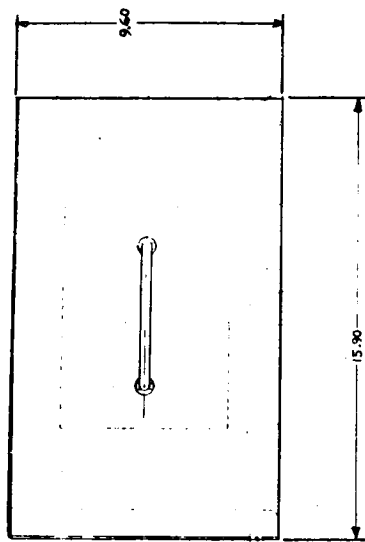


FIGURE 36 Skylab Astronaut Tool Kit

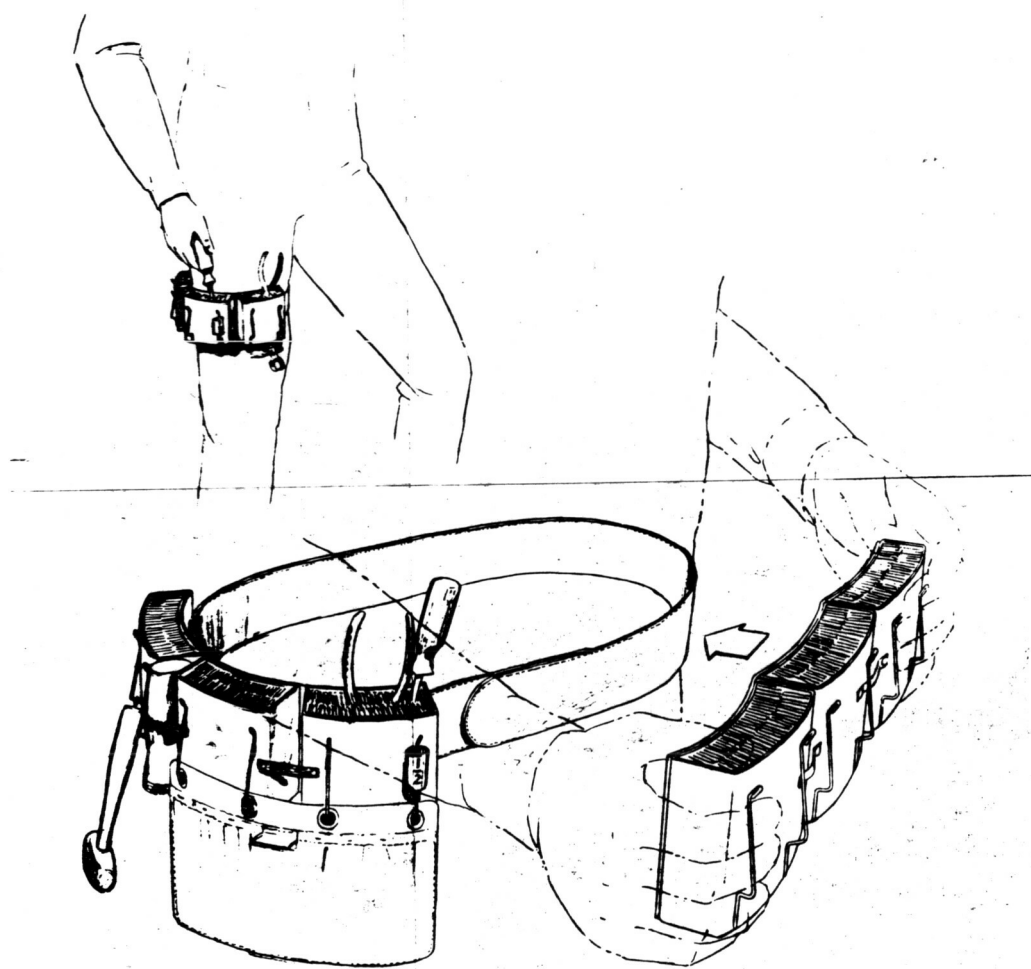


FIGURE 37 Skylab Tool Carrier

TABLE XIII

REPRESENTATIVE PARTS REQUIRING WORKSITE RETENTION

<u>NOMENCLATURE</u>	<u>SIZE(IN)</u>	<u>WEIGHT(LB)</u>
LST Secondary Mirror Module	29 Dia x 20	120
LST RCS Module	21 x 27 x 14	170
LST Solar Cell Assy	10 Dia x 132	90
Contamination Gage	1.3 Dia x 3.5	.5
Mass Spectrometer End Instrument	4 Dia x 6	2
Active Cleaning Device	8 Dia x 18	5
Small Film Magazine	6 x 9 x 6	5
Large Film Magazine	15 x 50 x 20	45
Antenna Dish Segment	114 x 180 x 18	20
Temperature Sensor	1.8 x 10 x 11	15
Fluxgate Magnetometer	6 x 6 x 6	5
AC Electric Field Sensor	(2.5 ft ³)	30
DC Electric Field Sensor	9 x 9 x 12	20
Electron Sensor	6 Dia x 1	3
ION Trap	5.6 Dia x 1	5.5
Proportional Counter Array	15 x 26 x 66	166
Scintillation Counter	20 x 30 x 27	286
Crystal Spectrograph	29 x 64 x 28	117

1. Permanent lighting be provided for all planned EVA/IVA handrail translation paths and worksites with the illumination levels used on Skylab.

2. That portable lighting assemblies be provided for all unscheduled EVA/IVA capable of supplying the illumination levels used on Skylab.

3. Solid mounting be provided at all planned worksites for equipment retention where possible.

4. Equipment be retained by tether to attach points at the worksite if solid mounting cannot be provided.

5. Provide for retention of the Skylab tool kit at worksites where the required tools cannot be determined.

6. Where the required tools can be pre-determined prior to EVA/IVA, provide small pockets or pouches on the space suit.

1.4 Conceptual Design of Work Platform End Effector

A conceptual design was accomplished to define a Work Platform End Effector. Figure 38 is the General Arrangement resulting from this Conceptual Design.

The EVA crewman shown is 69-1/2 inches tall. This is a median based on the astronaut population to date in Reference 16. The tallest astronaut is 72-1/2 inches tall and the shortest 65-1/4 inches tall. The crewman is wearing the 8 psi space suit recommended by ILC Industries in Reference 16. The EVA crewman is wearing a EV Life Support System (EVLSS) and an Emergency Oxygen Pack (EOP) defined in Volume I. The packages have been contoured to conform to the space suit and reduce the EVA crewman's bulk.

Figures 39 and 40 show the contoured EVLSS and EOP components.

The Manipulator Arm shown is from a Rockwell International drawing which shows manipulator capabilities. The end of the manipulator arm shown is 9-1/2 inches in diameter and contains a TV camera and a floodlight on it. The smaller diameter extension projecting from the 9-1/2 inch tube can extend 24 inches from the position shown. The device on the end of the small tube is a device for connecting and disconnecting end effectors. The TV camera and floodlight allow remote connection and disconnection of the end effector.

The Work Platform structure is a trusswork of 1 inch diameter tubing for the back, sides and bottom. The structure is configured to accommodate the EVA suited crewman wearing an EVLSS and EOP.

On this structure foot restraint, worksite stabilization, tool kit, manipulator controls, lighting and spare part retention provisions are mounted.

The foot restraints are the same as those used on Skylab.

The four worksite stabilization devices are telescoping arms that are extensible to about 30 inches. The pads on the ends of the arms are electroadhesive devices with approximately 600 pound retention capability. As an alternate to the electroadhesive device a grappler type device could be used. The use of a grappler would require that a protrusion be provided at the worksite for attachment of the grapplers.

The telescoping arms would be positioned manually and the attachment and release actuation controls would be mounted on the telescoping arm body for hand or finger operation. Should this manual operation technique prove unacceptable during manned evaluations, electric or pneumatically powered

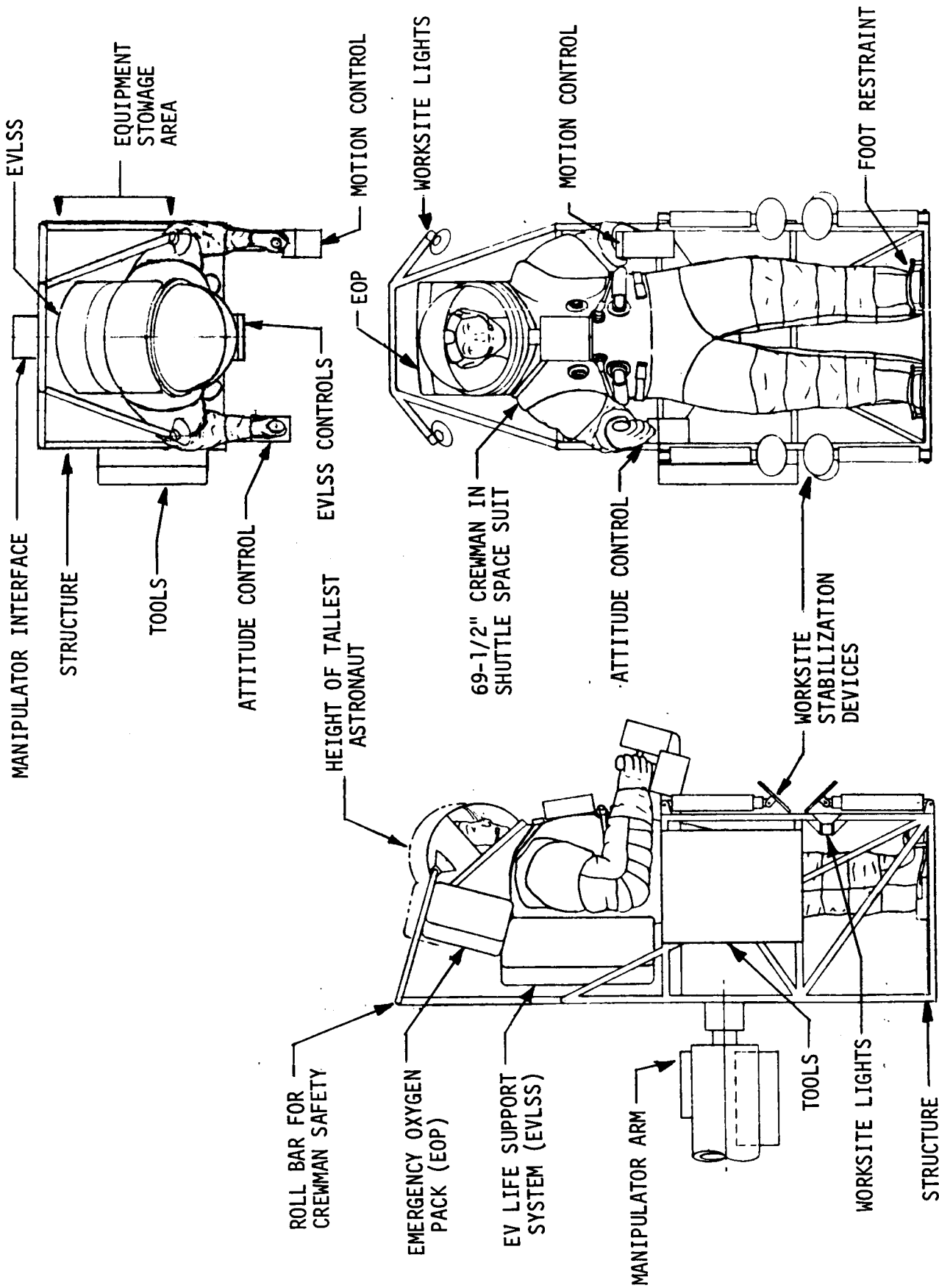


FIGURE 38 WORK PLATFORM END EFFECTOR GENERAL ARRANGEMENT

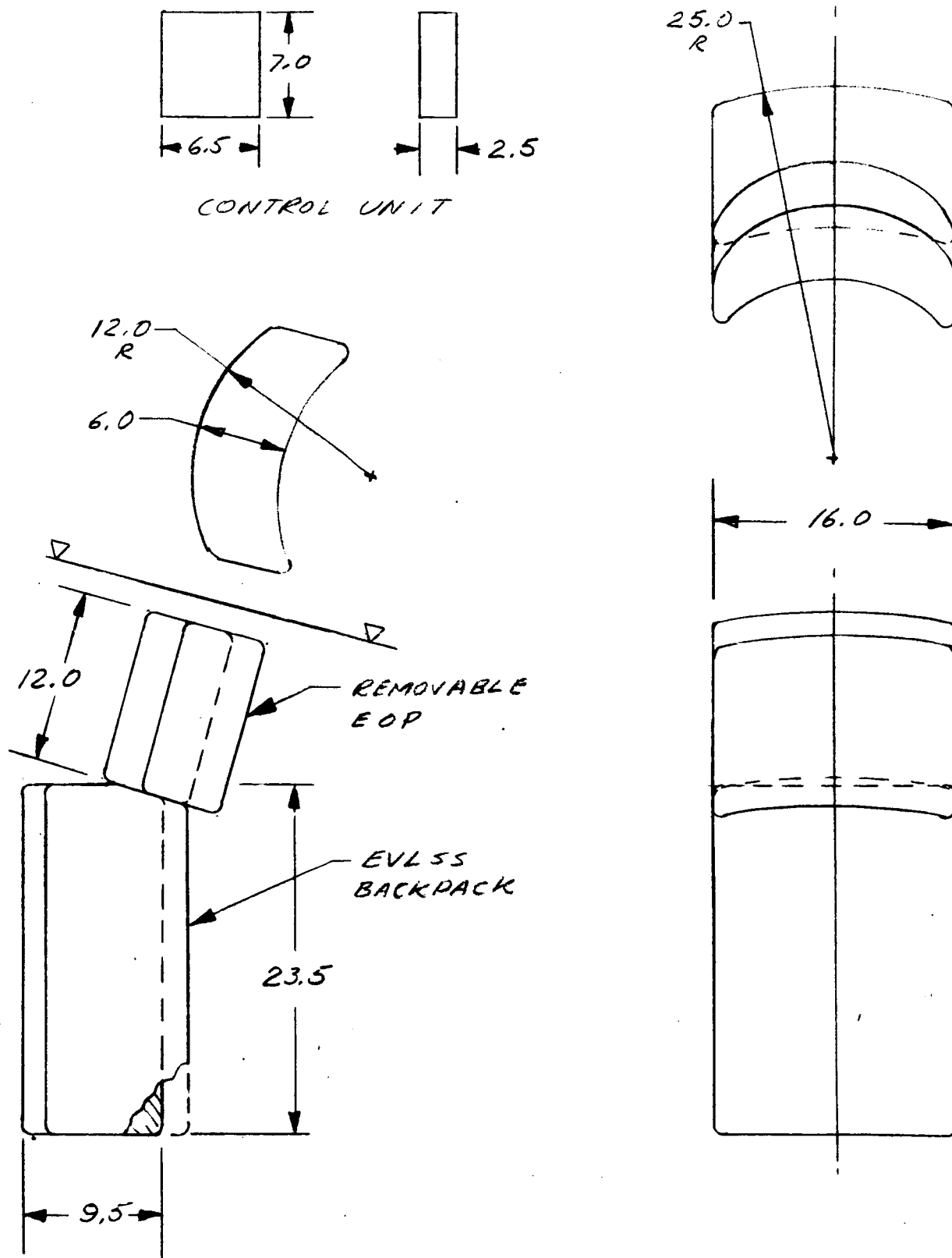


FIGURE 39 EVLSS BACKPACK, EOP AND CONTROL UNIT

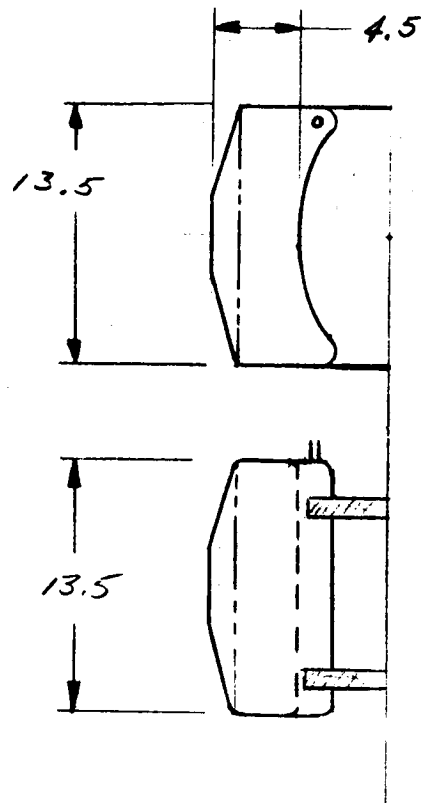


FIGURE 40 LEG MOUNTED ICE PACK

telescoping arms could be used and controlled using one remote hand operated controller.

The tool kit shown has the same volume as the Martin Skylab kit, Ref. 13. The tool kit shown would have two trays that could be pulled out the top and rotated outward approximately 45° to make the tools in each tray convenient to see and reach.

The manipulator controls are identical to the Apollo CM and LM flight controllers. The right hand controls rotation (roll, pitch and yaw) and the left hand controls movement (fore, aft, right, left, up down). The controls would be mounted such that each could be rotated out of the way while the crewman is performing his tasks at the worksite.

Two floodlight assemblies are shown over the crewman's shoulders and two about knee height for worksite illumination.

The side of the Work Platform end effector on the crewman's left would have provisions for attaching parts for transportation and retention.

The electrical interface with a manipulator arm would include electrical power for movement, extension, and adhesion^{*} of the worksite stabilization devices; signals between the manipulator controls on the Work Platform end effector and the control electronics; and power for the floodlight assemblies.

Figure 41 shows the Work Platform end effector attached to a small satellite and positioned for the EVA crewman to perform tasks on the satellite.

Figure 42 shows the Work Platform end effector attached to the aperture end of the LST for the EVA crewman to replace the Secondary Mirror

^{*} Could be small portable batteries

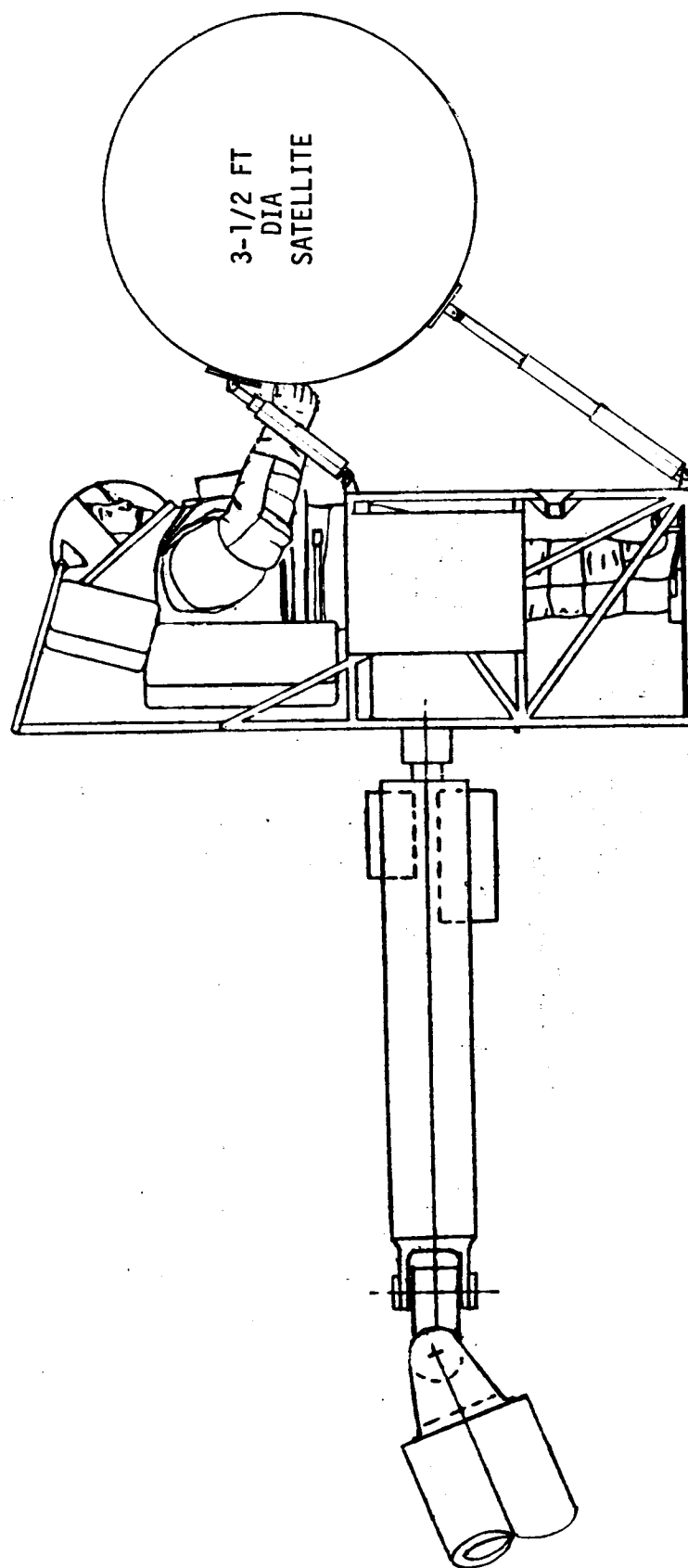


FIGURE 41 WORK PLATFORM END EFFECTOR AT SMALL SATELLITE WORKSITE

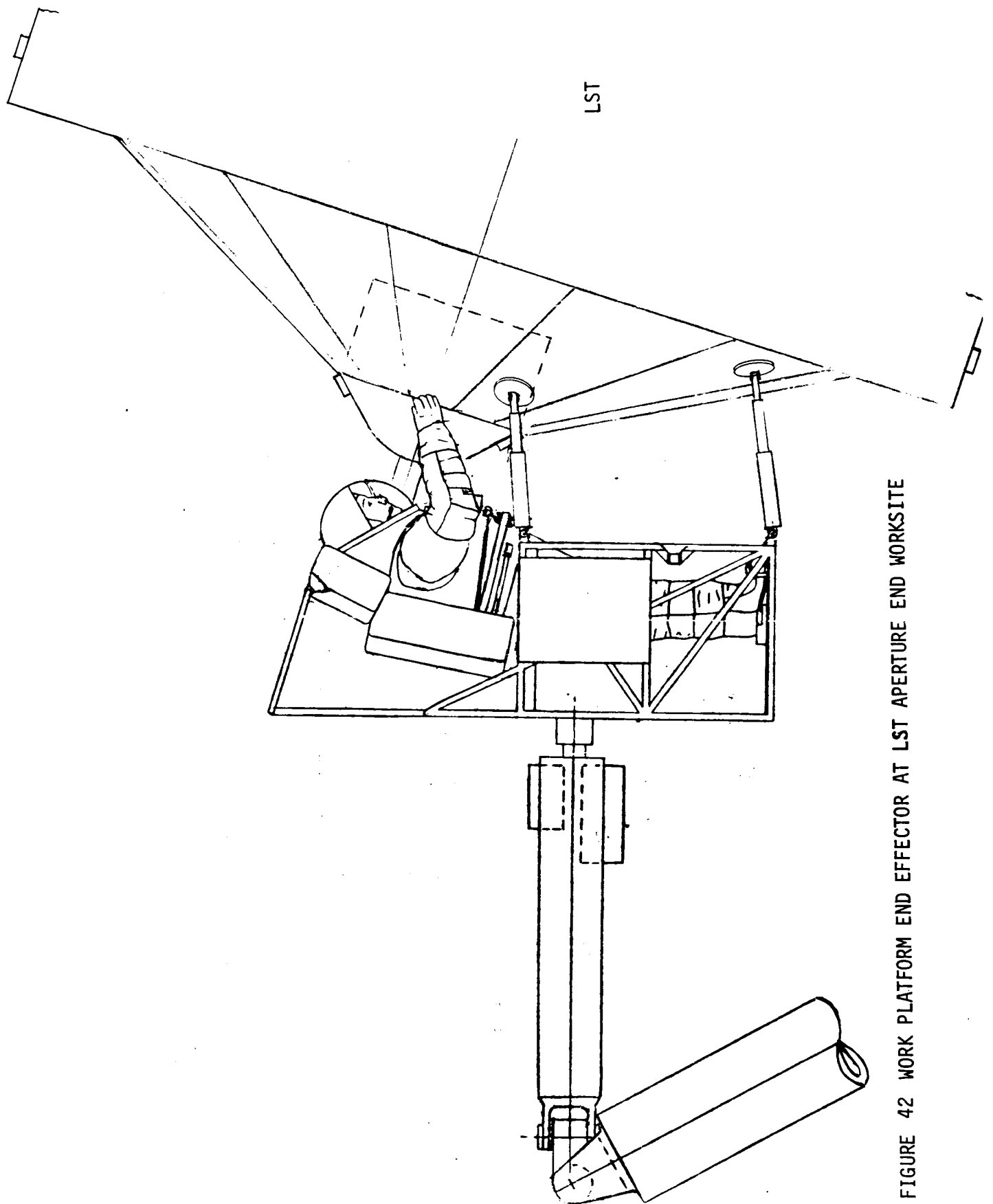


FIGURE 42 WORK PLATFORM END EFFECTOR AT LST APERTURE END WORKSITE

Module, Contamination gages and the Spectrometer end instrument, scenario 1A, Ref. 15. The sunshield is retracted and the environmental protection doors are closed for shuttle servicing.

Figures 43 and 44 show the Work Platform end effector attached to the LST for the EVA crewman to replace a solar cell panel assembly, scenario 1D, Ref. 15. The solar cell panel assembly is rolled up and rotated to a stowed position along the LST longitudinal axis for shuttle servicing.

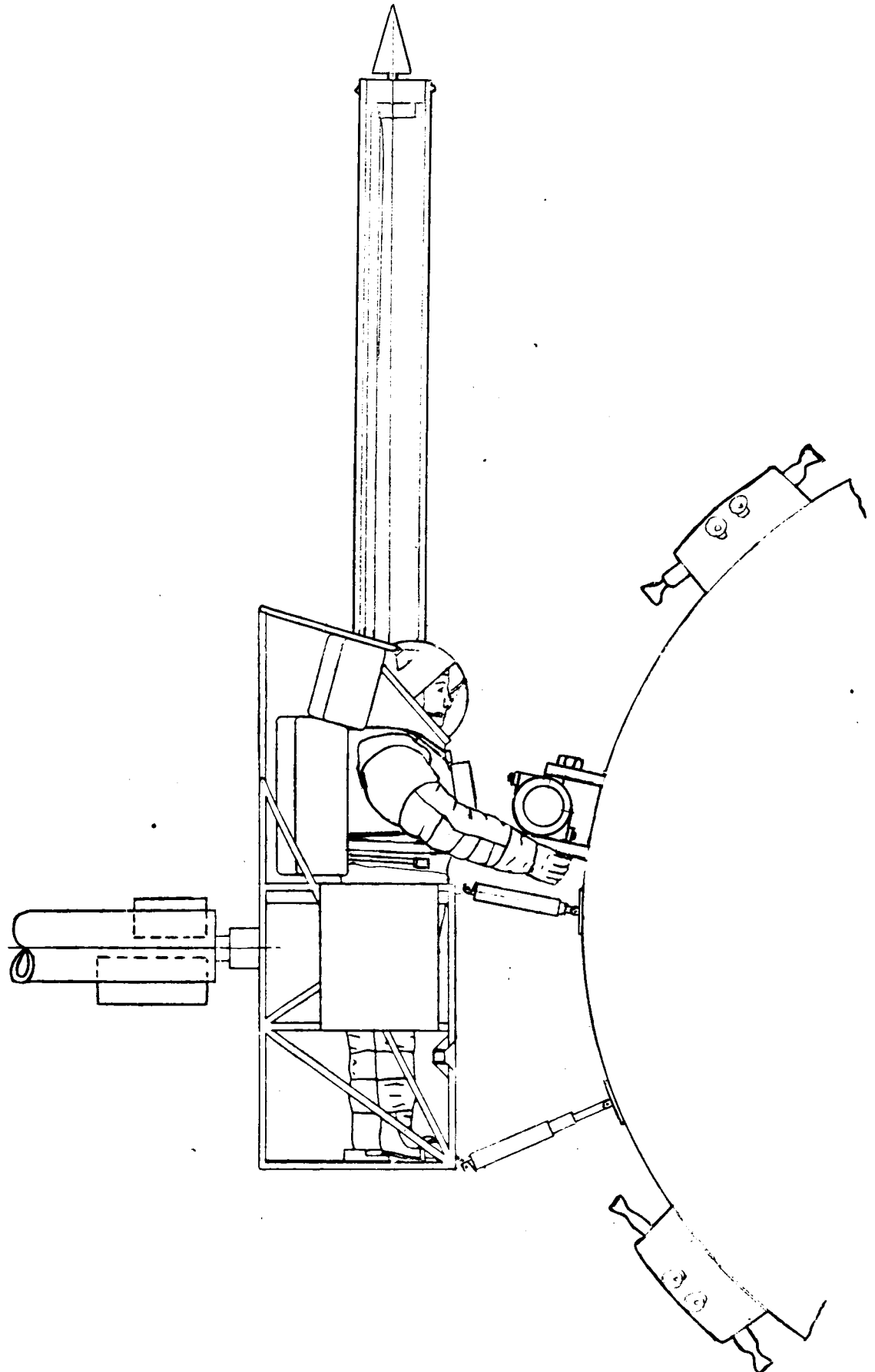


FIGURE 43 WORK PLATFORM END EFFECTOR AT LST SOLAR CELL ASSY WORKSITE SIDEVIEW

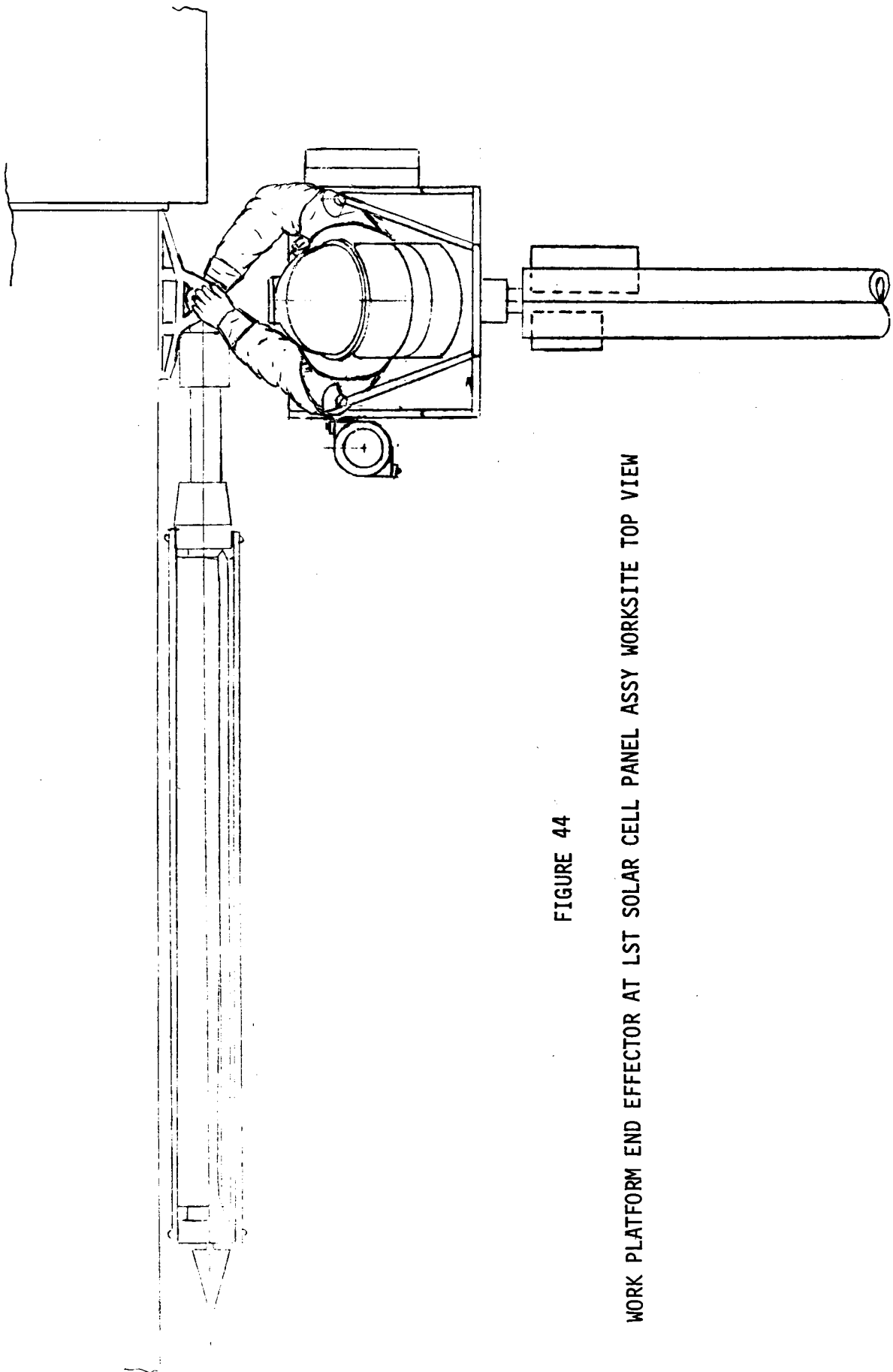


FIGURE 44
WORK PLATFORM END EFFECTOR AT LST SOLAR CELL PANEL ASSY WORKSITE TOP VIEW

2.0 MOBILITY AIDS REQUIREMENTS

Requirements are given for each of the mobility aids recommended in Section 1.0 for use on the Shuttle program. For each of the following a description of the item and a definition of the characteristics which the item must possess are given.

- o Work Platform End Effector
- o Handrails and Handholds
- o Cargo Pockets
- o Foot Restraint
- o Tethers
- o Lighting
- o Worksite Equipment Retention
- o Cargo Transfer End Effector
- o Electroadhesive Devices
- o Maneuvering Work Platform*

2.1 Work Platforms End Effector

2.1.1 Definition - The Work Platform End Effector is a terminal device for the Orbiter Attached Manipulator System (AMS) which will provide a means of translation for an EVA crewman and any equipment which he may require from a cabin airlock opening to any worksite within the AMS reach envelope. It will provide a work platform from which the crewman may perform his EVA tasks at the worksite. One Work Platform End Effector would be supplied on each Orbiter flight where EVA is planned or unscheduled EVA is anticipated.

2.1.2 Physical Characteristics

2.1.2.1 Interface with Orbiter Vehicle - The Work Platform End Effector will be stowed in the Orbiter Payload Bay where it may be remotely attached to the

* Required only if Orbiter contamination cloud precludes docking with some payloads.

AMS and brought to the cabin airlock exit for crewman ingress. The Work Platform End Effector stowage volume shall be held to a minimum. (Estimated size - 53 in. x 35.5 in. x 15.5 in.).

2.1.2.1.1 Weight - The Work Platform End Effector weight shall be 45 pounds maximum.

2.1.2.1.2 Environment - The Work Platform End Effector stowage environment and operating environment are given in Ref. 19.

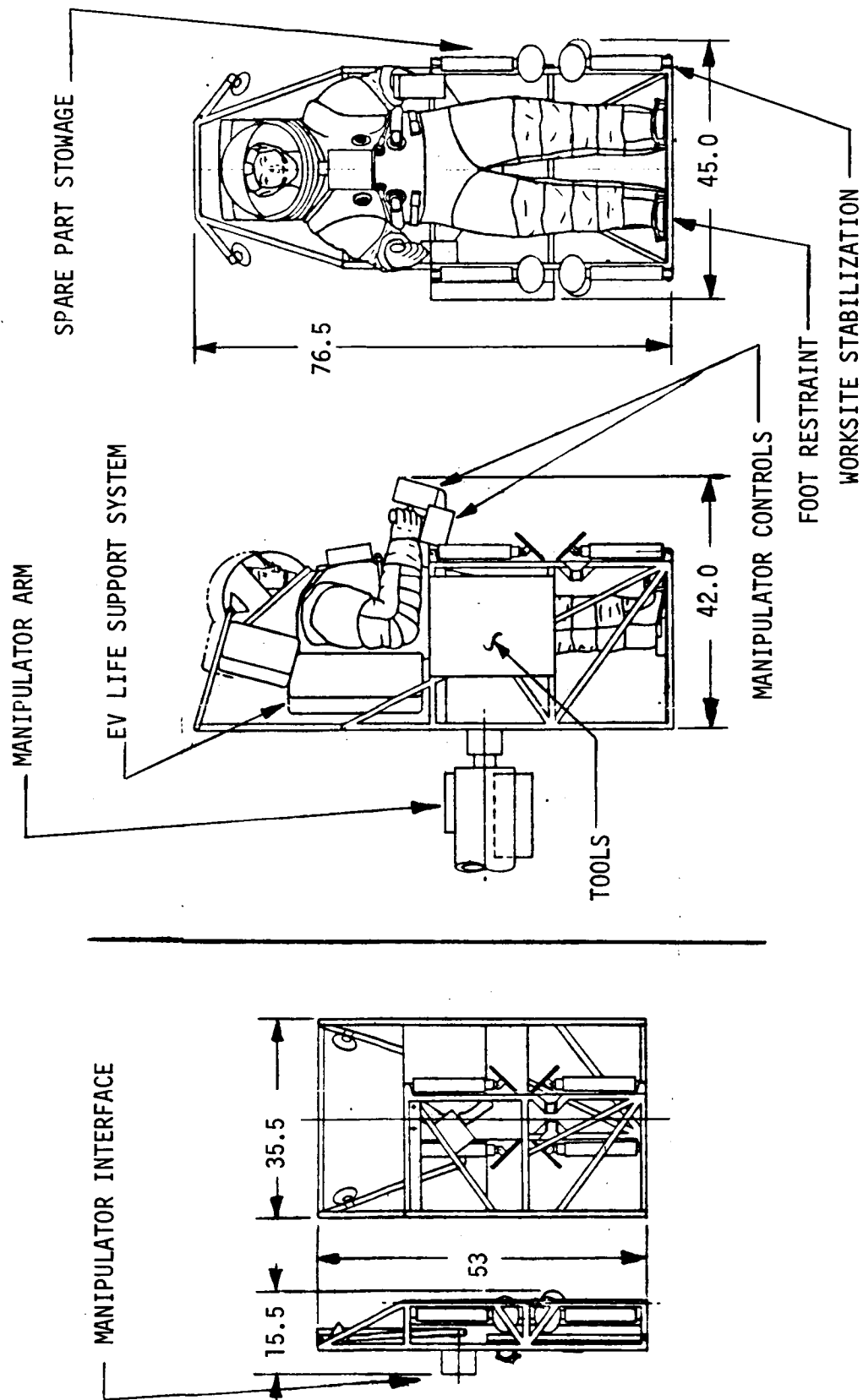
2.1.2.1.3 Interface with AMS - The Work Platform End Effector shall interface with the AMS described in Ref. 18.

The mechanical interface shall accommodate the remote attachment and detachment of the Work Platform End Effector at the stowage site in the payload bay. The electrical interface shall provide for electrical power for Work Platform End Effector lighting and worksite stabilization and for electrical signals between the Work Platform End Effector manipulator controls and the Orbiter manipulator control electronics.

2.1.2.2 General Arrangement - The general arrangement of the Work Platform End Effector is shown in Figure 45. It shall accommodate any NASA astronaut performing EVA tasks while wearing an Orbital EVA Space Suit and an EV Life Support System. The Work Platform End Effector shall cause no interference to the crewman's limb motion during the performance of his EVA tasks.

2.1.2.2.1 Orbital EVA Space Suit - The space suit to be accommodated is the Shuttle EVA suit recommended in Ref. 16, for the Apollo Crew Sizing History given.

2.1.2.2.2 EV Life Support System - Figure 46 shows how the EV Life Support System fits on the space suit and the overall dimensions of a crewman wearing the space suit and EVLSS. The EVLSS shown in Figure 46 is in four pieces (See Figures 39 and 40).



STOWED

MANNED

FIGURE 45 WORK PLATFORM END EFFECTOR - STOWED & MANNED

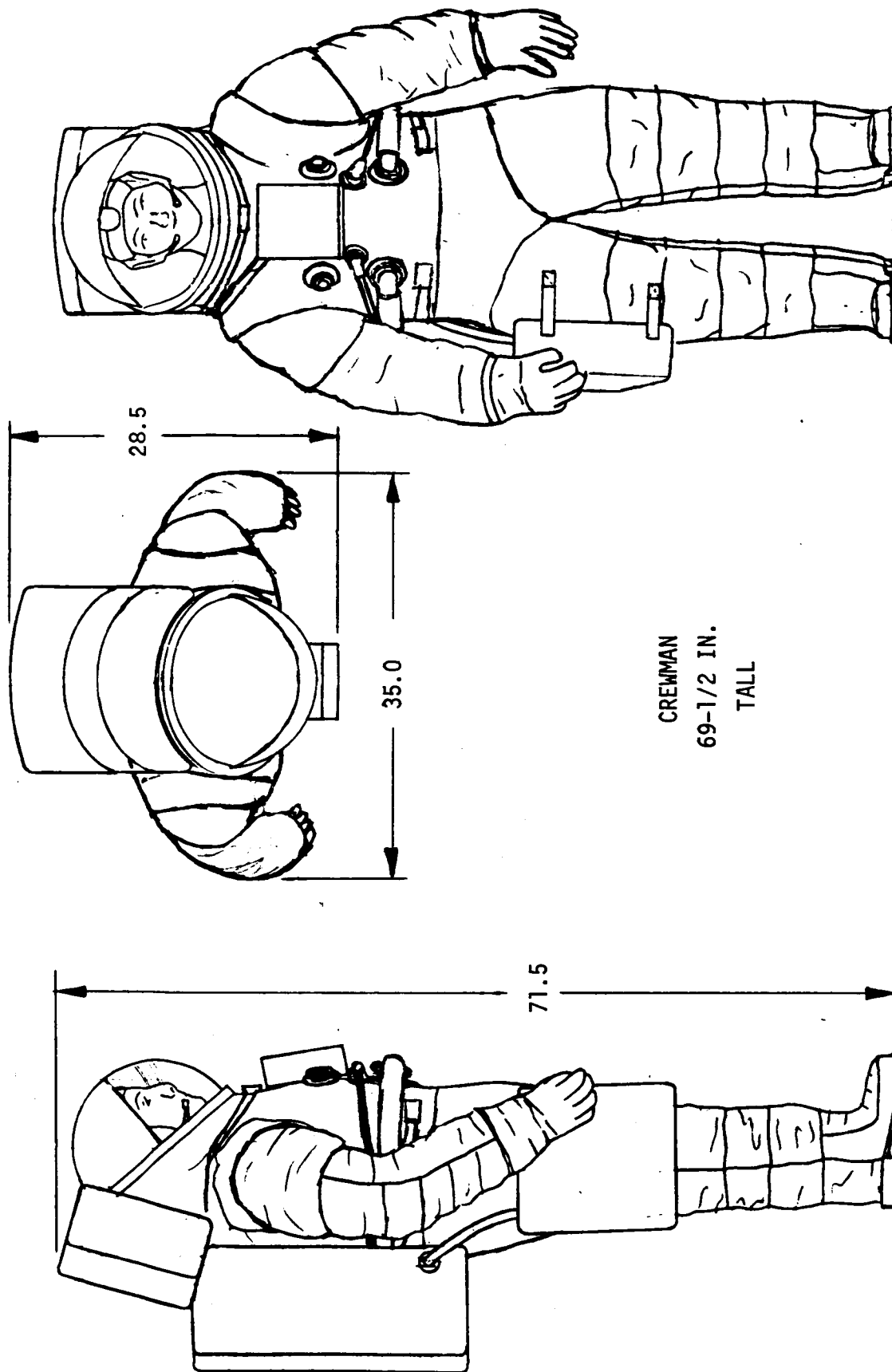


FIGURE 46 SHUTTLE SPACE SUIT AND EVLSS

The EOP, EVLSS backpack, and control unit are required for all EVA. The leg mounted Ice Pack is a non-venting heat sink used as required to prevent water vapor contamination of a worksite. The ice module portion of the Ice Pack will require replacement on EVA's of a duration over approximately one hour. It is, therefore, necessary to provide for stowing two replacement ice modules on the Work Platform End Effector within easy reach of the EVA crewman. An ice module is 12.5 in. x 12.5 in. x 3.1 in. and weighs 26.4 pounds.

2.1.2.2.3 Limb Motions - The limb motions of a suited EVA crewman are those recommended as Shuttle EVA suit requirements in Ref. 16.

2.1.2.3 Work Platform Positioning Controls

Controls shall be installed on the Work Platform End Effector for the EVA crewman to use in commanding Work Platform End Effector movements (fore, aft, up, down and side to side) and attitude (roll, pitch and yaw). The positioning controls may be combined into a one hand controller or separated, as they are for vehicle control, so that the left hand commands movements and the right hand commands attitude. The choice of controllers shall be based upon simulator evaluations.

If the positioning controls extend beyond the forward limit of Work Platform End Effector structure, provisions shall be made for positioning them such that they do not interfere with the EVA crewman during the performance of his tasks.

2.1.2.4 EVA Crewman Restraint - Skylab type foot restraint and attach points for safety waist tethers such as those shown in Ref. 2 shall be provided on the Work Platform End Effector.

2.1.2.5 Spare and Replaced Part Retentions - Space and the means of retaining the groups of cargo shown in Table XIV on the Work Platform shall be

provided. Also a means shall be provided on the Work Platform for temporary retention of any piece of equipment listed in Table XIV while a like part is being removed from the Work Platform and installed.

2.1.2.6 Tool Retention - The Skylab tool kit defined in Ref. 13 shall be mounted on the Work Platform where it will be easily accessible to the EVA crewman while he is accomplishing his tasks. Means for temporary individual tool retention shall also be provided.

2.1.2.7 Lighting - Light assemblies shall be provided on the Work Platform to illuminate the Work Platform and the worksite to a level of 5.0 ft. lamberts in accordance with Ref. 14.

2.1.2.8 Stabilization - A means shall be provided on the Work Platform for attaching to rigid structure at the worksite to stabilize the Work Platform while the EVA crewman accomplishes his tasks. The stabilization means shall be simple to position, attach, release and stow and have a minimum impact on the worksites. The stabilization attachments shall hold the Work Platform firmly in place while the EVA crewman applies the maximum sustained and impulse force emissions specified in Ref. 17.

2.2 Handrails and Handholds

2.2.1 Description - Handrails will provide a means for IVA crewmen and EVA crewmen outside the reach of the AMS to manually translate from place to place in zero G. Single handrails shall be provided for crew translation where the cargo packages being manually transported have a moment of inertia less than 15 slug-Ft² and/or a weight less than 300 pounds. Dual handrails shall be provided where the cargo packages being manually transported have a moment of inertia over 15 slug-Ft² and/or a weight greater than 300 pounds.

TABLE XIV CARGO GROUPS FOR WORK PLATFORM RETENTION

<u>QUANTITY</u>	<u>NOMENCLATURE</u>	<u>SIZE(IN.)</u>	<u>WEIGHT(LB)</u>
<u>Group I</u>			
1 ea.	Secondary Mirror Module	29 Dia x 20	120
6 ea.	Contamination Mon. Gages	1.3 Dia x 3.5	.5
2 ea.	Mass Spect. End Inst.	4 Dia x 6	2
<u>Group II</u>			
1 ea.	Active Cleaning Device	8 Dia x 18	5
4 ea.	Contamination Mon. Gages	1.3 Dia x 3.5	.5
1 ea.	Active Cleaning Agent Supply		
<u>Group III</u>			
2 ea.	RCS Module	21 x 27 x 14	170
<u>Group IV</u>			
1 ea.	Solar Cell Assy.	10 Dia x 132	90
<u>Group V</u>			
4 ea.	Small Film Magazine	6 x 9 x 6	5
1 ea.	Large Film Magazine	15 x 50 x 20	45
<u>Group VI</u>			
10 ea.	Antenna Dish Segments	114 x 180 x 18	20
<u>Group VII</u>			
1 ea.	Gas Temp. Sensor	1.8 x 10 x 11	15
1 ea.	Fluxgate Magnetometer	6 x 6 x 6	5
1 ea.	AC Elect. Field Sensor	2.5 ft ³	30
1 ea.	DC Elect. Field Sensor	9 x 9 x 12	20
1 ea.	Suprathermal Electron Sensor	5.6 Dia x 1	3
1 ea.	Ion Trap	5.6 Dia x 1	5.5

Handholds may be provided to aid the crewman in positioning himself in restraints or in resisting motion in some particular situation.

2.2.2 Physical Characteristics - The physical characteristics of handrails and handholds are shown in Table I. Dual handrails will be positioned 18 inches apart, center to center, Ref. 3.

2.3 Cargo Pockets

2.3.1 Description - Cargo pockets are pockets attached to the space suit which will allow a crewman to carry small cargo packages.

2.3.2 Physical Characteristics - One cargo pocket shall be capable of containing one cargo package or several cargo packages having a maximum volume of 125 in³ and a maximum weight of 4 pounds.

The pockets shall be removable. A maximum of six pockets will be used on one space suit simultaneously.

2.4 Foot Restraint

2.4.1 Description - Foot restraint is to be used at each work station to counteract loads applied by the crewman while performing his tasks.

2.4.2 Physical Characteristics - Existing Skylab foot restraint assembly shown in Ref. 8.

2.5 Tethers

2.5.1 Description - Safety tethers will be provided as necessary to prevent a crewman from inadvertently drifting away from the spacecraft during EVA. Retention tethers will be provided to prevent loose items being carried by crewmen from drifting away during EVA and IVA.

2.5.2 Physical Characteristics

2.5.2.1 Safety Tether - Safety tethers shall be waist tethers similar to those used on Gemini XII, Ref. 2.

2.5.2.2 Retention Tethers - Retention tethers shall be similar to those used on Apollo for retention of equipment during transearth EVA.

2.5.2.3 Attachments - All tether attachments which the crewman must operate shall be of the same design, requiring the same motions to activate.

2.6 Lighting

2.6.1 Description - Adequate lighting shall be provided for manual crew translation paths and worksites.

2.6.2 Physical Characteristics - Lighting shall illuminate each manual crew translation path with a minimum of 2.0 ft. lambert and each worksite with a minimum of 5.0 ft. lambert. The lighting shall be in accordance with Ref. 14. Portable lighting assemblies may be provided for illumination of unscheduled manual crew translation paths and worksites.

2.7 Worksite Equipment Retention

2.7.1 Description - Worksite equipment retention shall be provided to prevent loose parts and other equipment at the worksite from drifting away when they are not in use.

2.7.2 Physical Characteristics - The equipment to be retained will be different for each worksite. The equipment will include spare parts, removed parts which are to be replaced, replaced parts, tools and checkout equipment. Examples of parts which must be retained are given in Table XIV and the tools and tool kit which must be retained are described in Ref. 13. The equipment necessary at each worksite shall be retained, in a position where the crewman may utilize it as required, by temporarily attaching it to a solid mounting where possible. Where it is not possible to provide a solid mount, a tether as described in Section 2.5 shall be used for retention.

2.8 Cargo Transfer End Effector

2.8.1 Description - The Cargo Transfer End Effector is a terminal device for the Orbiter Attached Manipulator System (AMS) which will provide a means of transferring cargo from stowage in the payload bay to any worksite within the AMS reach envelope.

2.8.2 Physical Characteristics

2.8.2.1 Cargo Definition - The cargo to be handled is that defined in Ref. 18 plus package size down to 125 in³ and package weights down to 1 pound.

2.8.2.2 Interface with AMS - The Cargo Transfer End Effector shall interface with the AMS described in Ref. 18.

2.8.2.3 Interface with Orbiter Vehicle - The Cargo Transfer End Effector will either be stowed on the AMS or in the Orbiter payload bay where it may be remotely attached to the AMS.

2.9 Electroadhesive Devices

2.9.1 Description - Electroadhesion is an electrostatically induced attractive force between surfaces. Electroadhesive devices use this attractive force to attach handholds, boots and temporary mounting plates on the surfaces of spacecraft.

2.9.2 Physical Characteristics

2.9.2.1 Electroadhesive Handholds - The handle shall have approximately the same characteristics as those given for handholds in Table I. The switch to turn the attractive force on and off shall be on the handle. The Electroadhesive Handhold shall have a self contained power supply.

2.9.2.2. Electroadhesive Shoes - The Electroadhesive device for boots shall mate with the Orbital EVA Space Suit boots, Ref. 16. The switch to turn the attractive force on and off shall be hand operated, right foot right hand, left foot left hand. The electroadhesive device for boots shall have a

self-contained power supply.

2.9.2.3 Electroadhesive Temporary Mounting Plate - This device shall be capable of having a variety of attachment hardware installed on it. Examples of the attachment hardware anticipated are rings for tether attachment, brackets for mounting parts and telescoping arms for work platform stability. The switch to turn the attractive force on and off shall be on the mounting plate, however, the capability for using a remote switch shall be built into the mounting plate. The Electroadhesive temporary mounting plate shall have a self-contained power supply.

2.9.3 Performance Characteristics - The attractive force for electro-adhesive devices shall be 600 pounds minimum when operating in a vacuum. The devices shall be capable of operating on a flat surface or the surface of a cylinder as small as 3 1/2 feet in diameter.

2.9.4 Electromagnetic Interference (EMI) - These devices shall cause no EMI which compromises Orbiter or payload communications or control.

2.10 Maneuvering Work Platform (MWP)

2.10.1 Definition - The Maneuvering Work Platform is a free flying vehicle which will provide the means for translation between the Orbiter vehicle and unattached orbiting payload. It will provide a work platform from which the crewman may perform his EVA tasks and a means of transporting and retaining the equipment required at the worksite. A Maneuvering Work Platform would be supplied on each Orbiter flight where EVA is planned involving free flight to a payload.

2.10.2 Physical Characteristics

2.10.2.1 Interface with Orbiter Vehicle - The maneuvering work platform will be stowed in the Orbiter payload bay. Provisions will be made for checkout of the MWP in the payload bay from the Orbiter cabin. The MWP stowage volume

shall be held to a minimum.

2.10.2.1.1 Weight - The MWP weight shall be held to a minimum.

2.10.2.1.2 Environment - The MWP stowage environment and operating environment are given in Ref. 19.

2.10.2.2. General Arrangement - The general arrangement of the MWP shall accommodate any NASA astronaut performing EVA tasks while wearing an Orbital EVA space suit and EV Life Support System. The MWP shall cause no interference to the crewman's limb motion during the performance of his EVA tasks.

2.10.2.2.1 Orbital EVA Space Suit - The space suit to be accommodated is the Shuttle EVA suit recommended in Vol. III, for the "Apollo Sizing History" given in that volume.

2.10.2.2.2 EV Life Support System - Figure 46 shows how the EV Life Support System fits on the space suit and the overall dimensions.

2.10.2.2.3 Limb Motions - The limb motions of a suited EVA crewman are those recommended as Shuttle EVA suit requirements in Vol. III.

2.10.2.2.4 MWP Maneuver Controls - Two control handles shall be installed on the MWP for the EVA crewman to use the control the MWP maneuvers, one to control movements (fore, aft, up, down and side to side) and one to control attitude (roll, pitch and yaw).

2.10.2.3 EVA Crewman Restraint - Skylab type foot restraints and attach points for safety waist tethers such as those shown in Ref. 2 shall be provided on the MWP at the control station and each work station.

2.10.2.4 Spare and Replaced Part Retention - Space and the means of retaining the groups of cargo shown in Table XIV on the MWP shall be provided. Also a means shall be provided on the MWP for temporary retention of any piece of equipment listed in Table XIV while a like part is being removed from the MWP and installed.

2.10.2.5 Tool Retention - The Skylab tool kit defined in Ref. 13 shall be mounted on the MWP where it will be easily accessible to the EVA crewman while he is accomplishing his tasks. Means for temporary individual tool retention shall also be provided.

2.10.2.6 Lighting - Light assemblies shall be provided on the MWP to illuminate the MWP and the worksite to a level of 5.0 ft. lamberts minimum in accordance with Ref. 14.

2.10.2.7 Worksite Stabilization - A means shall be provided on the MWP for attaching to rigid structure at the worksite to stabilize the MWP while the EVA crewman accomplishes his tasks. The means shall be simple to operate for both attachment and release, and have a minimum impact on the worksites. The stabilization attachments shall hold the MWP firmly in place while the EVA crewman applies the maximum sustained and impulse force emissions specified in Ref. 17.

2.10.2.8 Communication - Provisions shall be made on the MWP for voice and biomed communications between the MWP and the Orbiter.

2.10.2.9 Tracking Aids - Visual and RF devices shall be on the MWP to aid the Orbiter in tracking or locating the MWP in space.

2.10.2.10 Free Flight Stabilization - Control Moment Gyros (CMG) shall be used on the MWP for commanded rotation and automatic attitude hold.

2.10.2.11 Propulsion - Compressed dry gas shall be used on the MWP as propellant for commanded translation and CMG momentum dump.

2.10.2.12 Life Support System - A MWP Life Support System shall be provided which will supply EV Life Support System expendables to extend the available EVA time. This will impact the baseline EVLSS design of Vol. I.

2.10.3 Performance Characteristics

2.10.3.1 MWP Life Support System - A Life Support System shall be on the

MWP which, when used in conjunction with the EV Life Support System, will provide for 8 hours of EVA plus 2 hours contingency for rescue, Ref. 6.

2.10.3.2 MWP Propulsion - The MWP propulsion shall provide for translating 2000 ft., worksite stabilization and return to Orbiter vehicle with adequate contingency. Translational accelerations:

Fore/Aft - 1.0 Ft²/Sec²

Vertical/Lateral - 0.5 Ft²/Sec² (Ref. 6)

2.10.3.3 MWP Stabilization - The MWP stabilization shall provide:

Stabilization and Control Deadband - $\pm 2^\circ$

Rotational Accelerations (Pitch, Roll & Yaw) -18°/Sec² Avg.

Rotational Command Rates (Pitch, Roll & Yaw) -15°/Sec Max.

3.0 MOBILITY AIDS VEHICLE SUPPORT PROVISIONS

3.1 Work Platform End Effector

3.1.1 Orbiter

3.1.1.1 Stowage - Provision shall be made in the Orbiter payload bay for stowage of the Work Platform End Effector in such a location as to have the interface with the AMS accessible for remote attachment. The Work Platform End Effector stowage volume is estimated to be 53 in. high, 35.5 in. wide and 15.5 in. deep (fore and aft). These stowage provisions shall include structural support during Orbiter launch, maneuvering, de-orbit and landing.

3.1.1.2 AMS Interface

1) Provision shall be made on one or both attached manipulator arms for remotely attaching the Work Platform End Effector, releasing it from its supports and positioning it at the cabin airlock.

2) Provisions shall be made in the AMS which will allow the EVA crewman on the Work Platform End Effector to control the movement of the AMS by control handles located on the Work Platform and Effector.

3) Provisions shall be made whereby the AMS will supply Orbiter electrical power for the Work Platform End Effector lighting. Work Platform lighting will be supplied by approximately (6) six 28 volt, 18.75 watt incandescent lamps (MS15584-16).

4) Provisions shall be made in the AMS whereby the Work Platform End Effector may be positioned on the surface of the Orbiter up to 150 ft. from the base of the manipulator arms.*

3.1.2 Payloads

3.1.2.1 Structural Interface - Each planned worksite shall contain provisions for the Work Platform End Effector to be attached to rigid structure

*Or, alternately, external mobility aids such as electroadhesors or burn-off handholds must be used.

for stabilization while the EVA crewman accomplishes his tasks.

3.1.2.2 Human Factors - For each planned worksite adequate access shall be provided on the payload for the EVA tasks to be accomplished. Payload items to be replaced or otherwise handled during EVA shall possess the characteristics necessary for ease in handling by the EVA crewman in his Orbital EVA Space Suit, Vol. III.

3.2 Handrails and Handholds

3.2.1 Orbiter

3.2.1.1 Structural Interface - Provisions shall be made in the Orbiter structure for mounting permanently, or temporarily as required, handrails and handholds. Each handrail and handhold mount shall support the limit loads given in Table I.

3.2.1.2 Stowage - Provisions shall be made in the Orbiter for stowage of any portable crew translation handrails or handholds required for EVA or IVA on an Orbiter flight.

3.2.2. Payloads

3.2.2.1 Structural Interface - Provisions shall be made in the payload structure for mounting permanently, or temporarily as required, handrails and handholds. Each handrail and handhold shall support the limit loads given in Table I.

3.2.2.2 Stowage - Provisions shall be made in the payload for stowage of any portable crew translation handrails or handholds required for EVA or IVA on that payload. The stowage area shall be close to the area where the items will be used to minimize the crew effort required.

3.3 Foot Restraint

3.3.1 Orbiter and Payload

3.3.1.1 Human Factors - Skylab type foot restraints shall be located

relative to each planned worksite to provide for an EVA crewman to accomplish the necessary tasks. If the foot rest is stowed in place or portable the mechanism for deploying and stowing shall be easy for an EVA crewman to operate.

3.3.1.2 Structural Interface - Provisions shall be made in the structure for mounting permanently, or temporarily as required, the Skylab foot restraints.

3.4 Tethers

3.4.1 Orbiter and Payload

3.4.1.1 Structural Interface - Provisions shall be made in the structure for attaching safety or cargo tethers where required. The attachments for safety tether shall support a limit load of 600 pounds in any direction. The attachments for cargo tethers shall be sized to support the particular cargo being retained.

3.5 Lighting

3.5.1 Orbiter

3.5.1.1 Stowage - Provisions shall be made in the Orbiter for stowage of portable light assemblies required for unscheduled EVA or IVA. A portable light assembly is estimated to be 3 in. x 3 in. x 6 in. and weigh 3 pounds.

3.5.1.2 Electrical Interface

3.5.1.2.1 Electrical Power - Provisions shall be made for each payload to be supplied Orbiter electrical power for the light assemblies at planned worksites and each manual translation path as required in 2.6.

3.5.1.2.2 Illumination Control - On-off controls shall be provided in the Orbiter for each worksite and manual translation path. These controls shall be located on the payload monitor control console.

3.5.1.2.3 Orbiter to Payload Electrical Connector - Provisions shall be made for automatically connecting and disconnecting the lighting electrical wiring from the Orbiter to the payload when the Orbiter docks and releases the payload.

3.5.2 Payload

3.5.2.1 Structural Interface - Provisions shall be made in the structure to mount the light assemblies for illumination of planned worksites and manual translation paths as required in 2.6.

3.5.2.2 Electrical Power - Electrical power for the planned worksite and manual translation path illumination will be supplied and controlled by the Orbiter. Provisions shall be made on the payload for routing the electrical power from the Orbiter to Payload Electrical Connector to the light assemblies.

3.5.2.3 Orbiter to Payload Electrical Connector - Provisions shall be made for automatically connecting and disconnecting the lighting electrical wiring from the Orbiter to the payload when the orbiter docks and releases the payload.

3.6 Worksite Equipment Retention

3.6.1 Payload

3.6.1.1 Structural Interface - Provisions shall be made in the structure to mount mating parts for attaching devices to retain equipment at planned EVA and IVA worksites as required in 2.7.

3.7 Electroadhesive Devices

3.7.1 Orbiter

3.7.1.1 Stowage - Provisions shall be made in the Orbiter for stowage of the Electroadhesive devices.

3.7.1.2 Electrical Power - Provisions shall be made in the Orbiter for recharging the self-contained power supply in each electroadhesive device

from Orbiter electrical power.

3.7.1.3 Conductive Layer - A conductive layer suitable for use with the electroadhesive devices shall be provided at planned Orbiter EVA/IVA worksites and along Orbiter EVA/IVA crew translation paths where the devices are to be used.

3.7.2 Payload

3.7.2.1 Conductive Layer - A conductive layer suitable for use with the electroadhesive devices shall be provided at planned payload EVA/IVA worksites and along payload EVA/IVA crew translation paths where the devices are to be used.

3.8 Maneuvering Work Platform (MWP)

3.8.1 Orbiter

3.8.1.1 Stowage - Provision shall be made in the Orbiter payload bay for stowage of the MWP. These stowage provisions shall include structural support during Orbiter launch, maneuvering, de-orbit and landing.

3.8.1.2 Checkout - Provision shall be made in the Orbiter for checkout of the MWP in the payload bay from the Orbiter cabin.

3.8.1.3 Access - Provisions shall be made for access by an EVA crewman between the cabin airlock opening and the MWP stowage area.

3.8.1.4 Communications - Provisions shall be made in the Orbiter for voice and biomed communications between the MWP and the Orbiter.

3.8.1.5 MWP Tracking - Provisions shall be made in the Orbiter for locating and tracking the MWP while it is in the free flight.

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APPENDIX A

APOLLO EVA HANDHOLD THERMAL ANALYSIS

APOLLO EVA HANDHOLD THERMAL ANALYSIS

EVA HANDHOLDS

Configuration

A total of ten EVA handholds are located on the crew and forward compartments, as shown in Figure 1. The components analyzed consist of handrails A, B, C, D, E, the deployable handrail, the unified hatch handrail, the handrail ring, and the two forward crew hatch flexible handles. The cross sections of the various configurations, on which the thermal models are based, are shown in Figures 2 through 7.

Analysis

A two-dimensional transient-heat-conduction analysis of the various handhold configurations was made for the HL-1 entry in order to predict the maximum bondline temperature during entry that occurred at the handhold and heat shield penetration. The preentry temperature was 150 F, except for the forward crew hatch flexible handles which are treated separately. It is assumed that the handrails will fall away when the aluminum base melts around the attachment bolts.

Thermal analysis of some of the preliminary handrail designs produced ablator bondline temperatures in excess of the maximum allowable of 600 F. These temperatures were significantly reduced by inserting 0.13-inch-thick copper discs between the fiberglass installation plugs and the steel face sheets, as shown in Figures 2 through 4. Additional temperature reductions were achieved by filling the bottom of the bolt attachment holes with RTV rubber, as shown in Figures 3 and 4.

The flexible handles attached to the forward combined crew hatch are constructed of woven nylon webbing except for the core of the grip portion which consists of polyurethane foam. The webbing straps penetrate through the ablator and are attached to the steel heat shield. The thermal model of the configuration analyzed is shown in Figure 7. As each handle is symmetrical and the heating environment is uniform, only one-half of a handle was required for study. The ends of the handle straps are sealed to the heat shield and, after installation of the molded Avcoat insulator blocks, the gaps between the straps and blocks are closed with RTV rubber seal. In the analysis, it was assumed there were no gaps between the straps and RTV rubber seal due to handling by the crew during space operations. Initial preentry temperatures of 135 F were used.

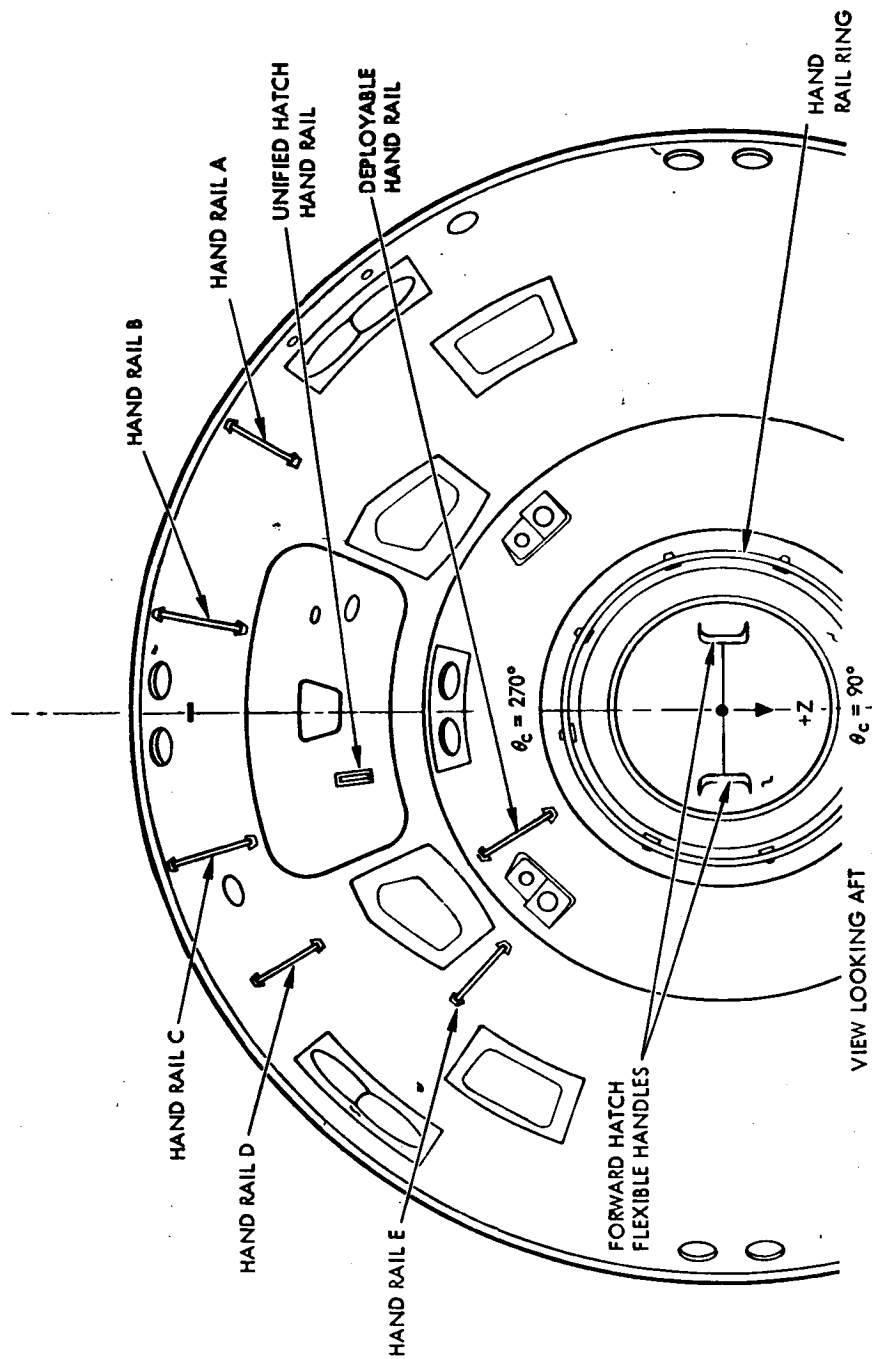


Figure 1. EVA Handhold Locations

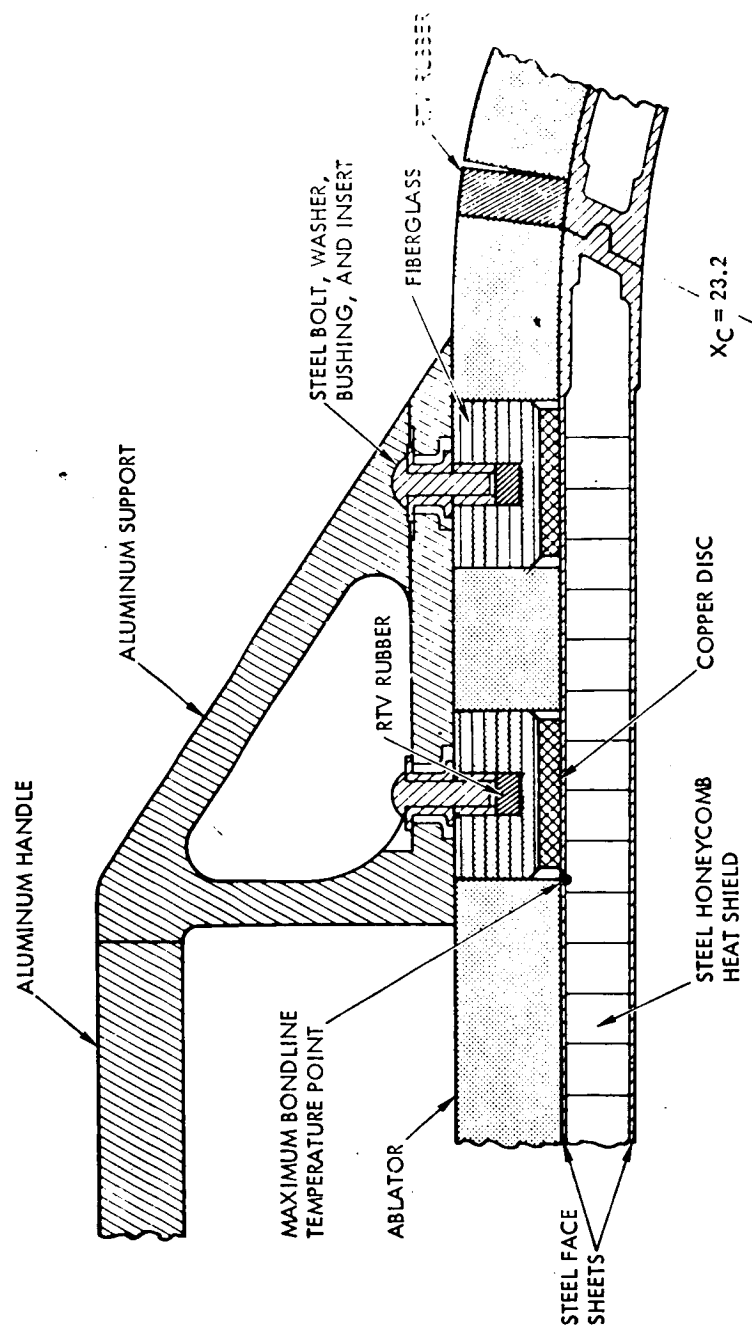


Figure 2. EVA Handrail, A, B, and C Models

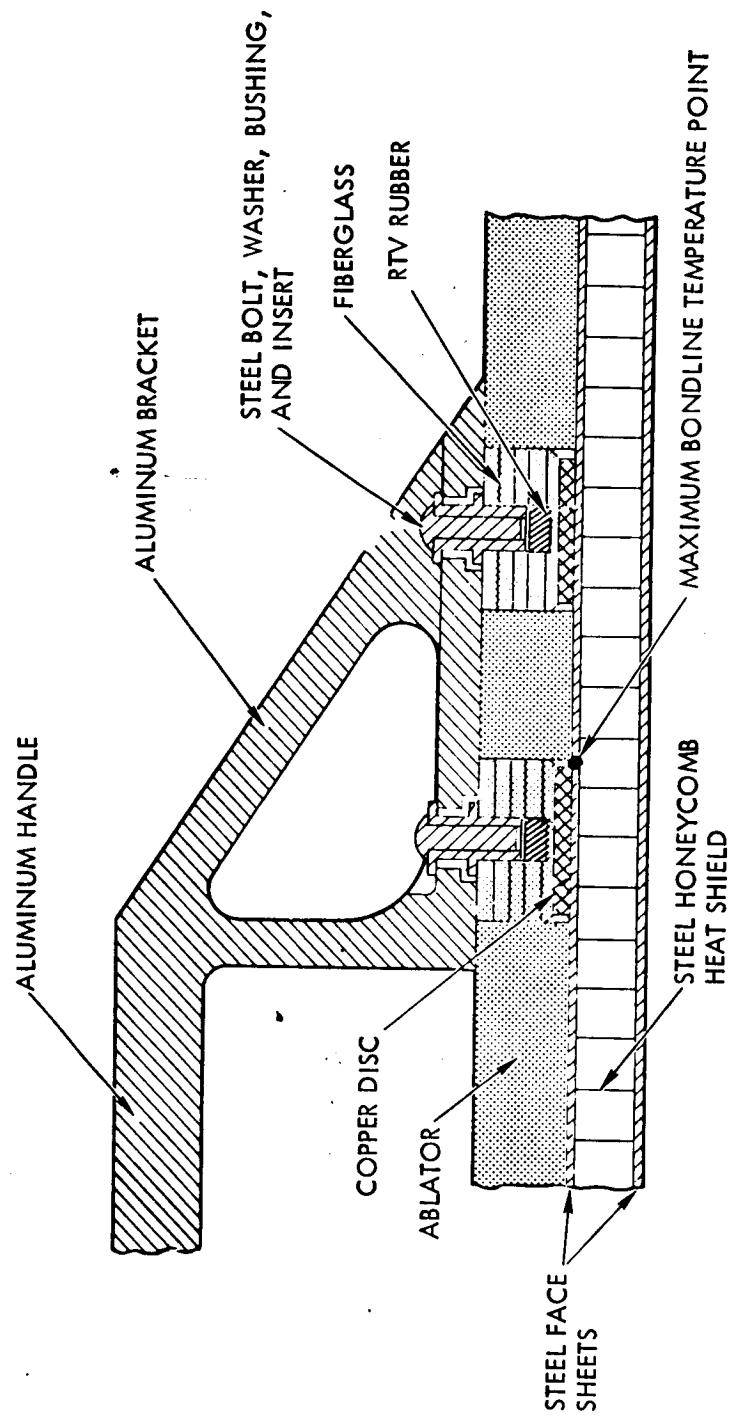


Figure 3. EVA Handrail, D and E Models

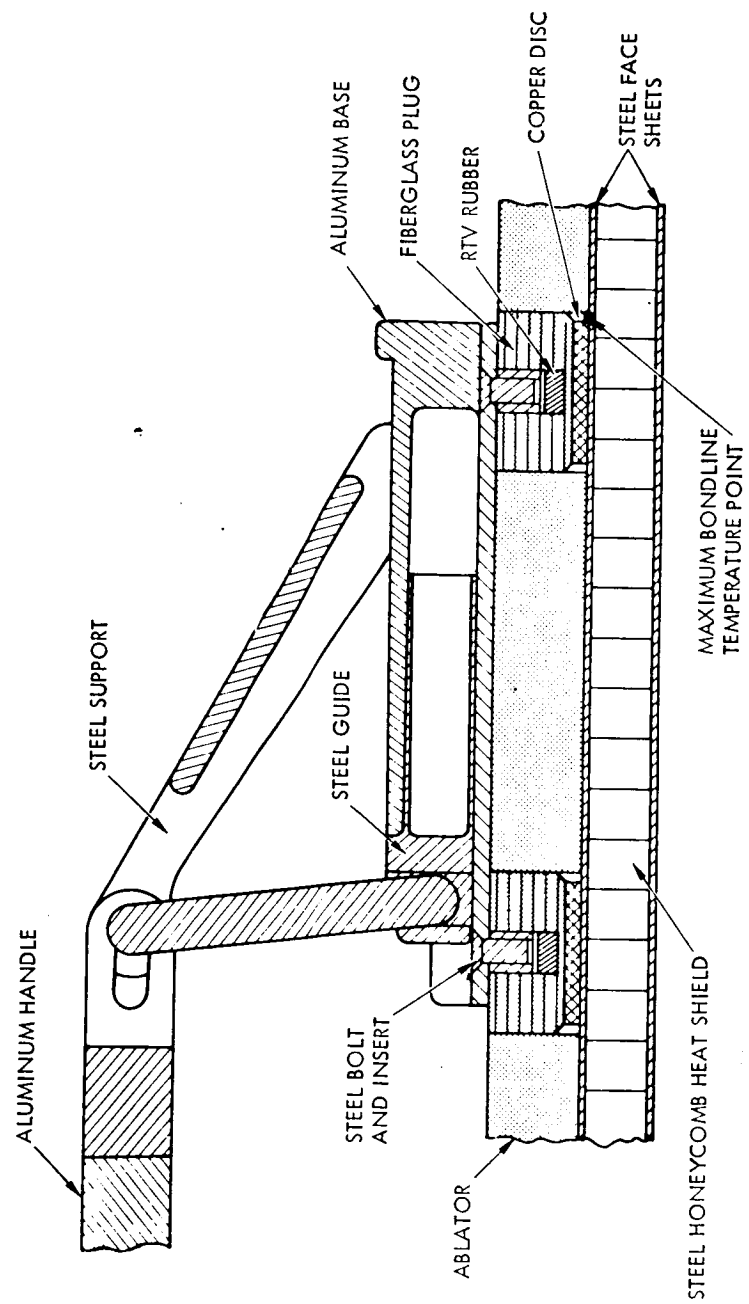


Figure 4. EVA Deployable Handrail

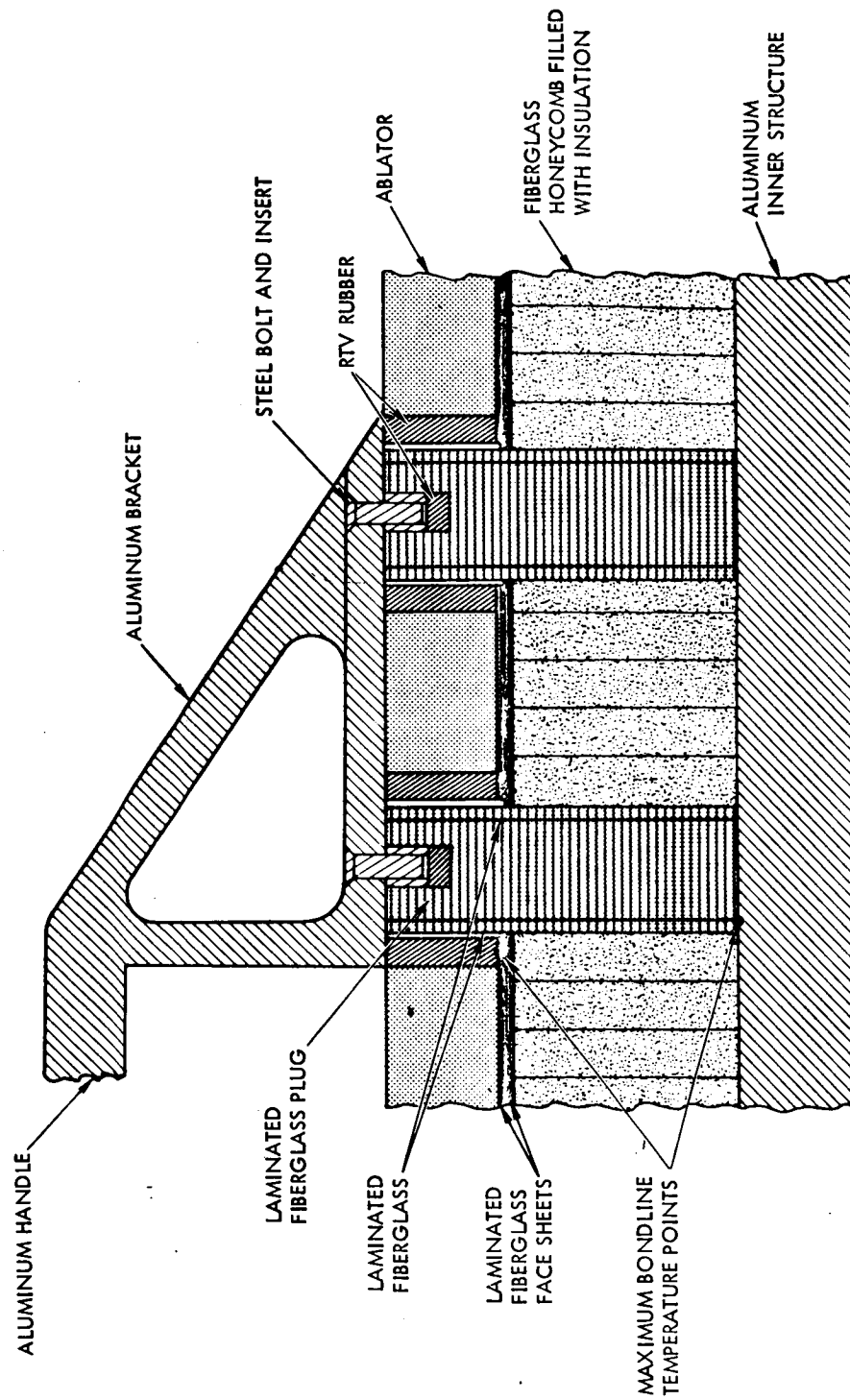


Figure 5. Unified Hatch EVA Handrail

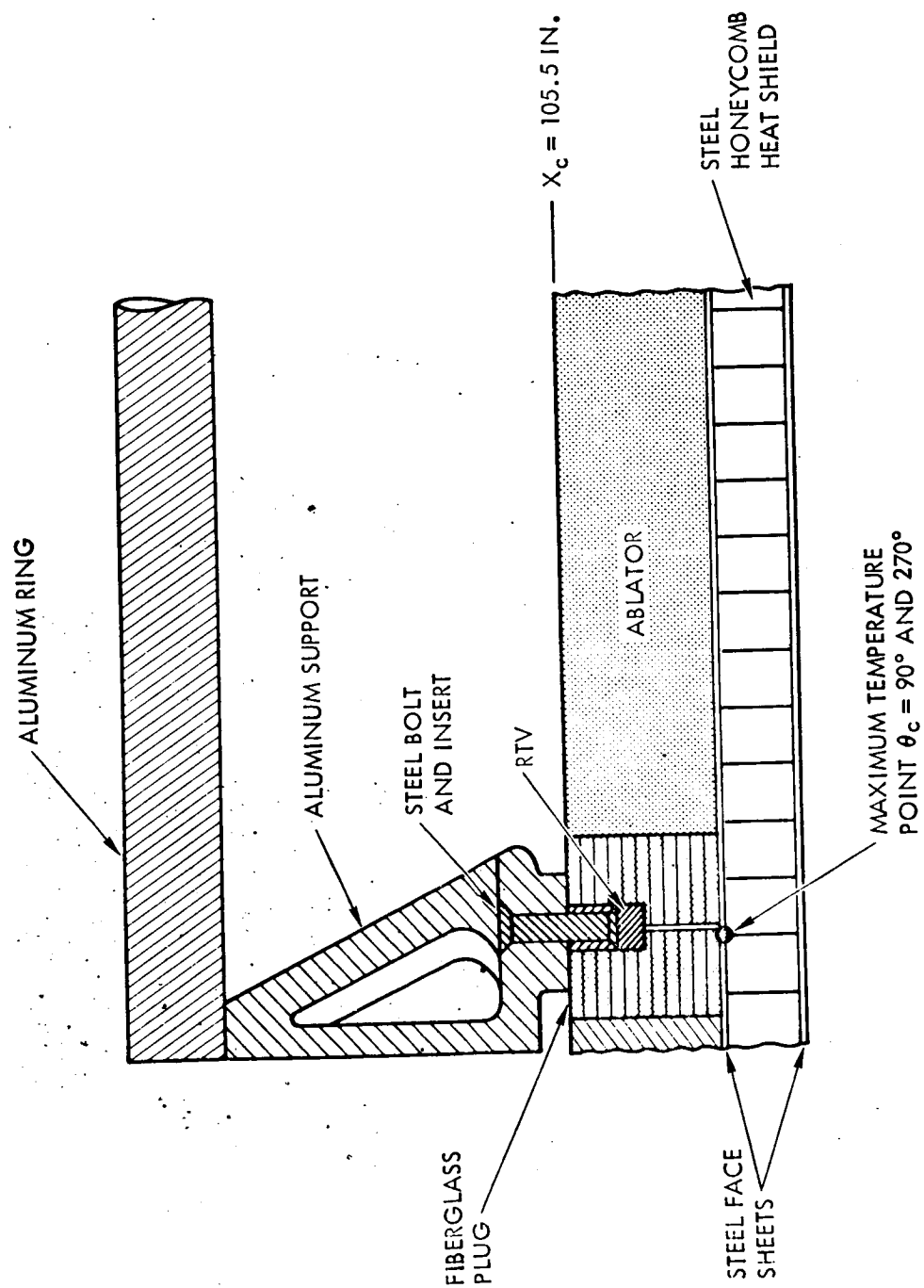


Figure 6. EVA Handrail Ring

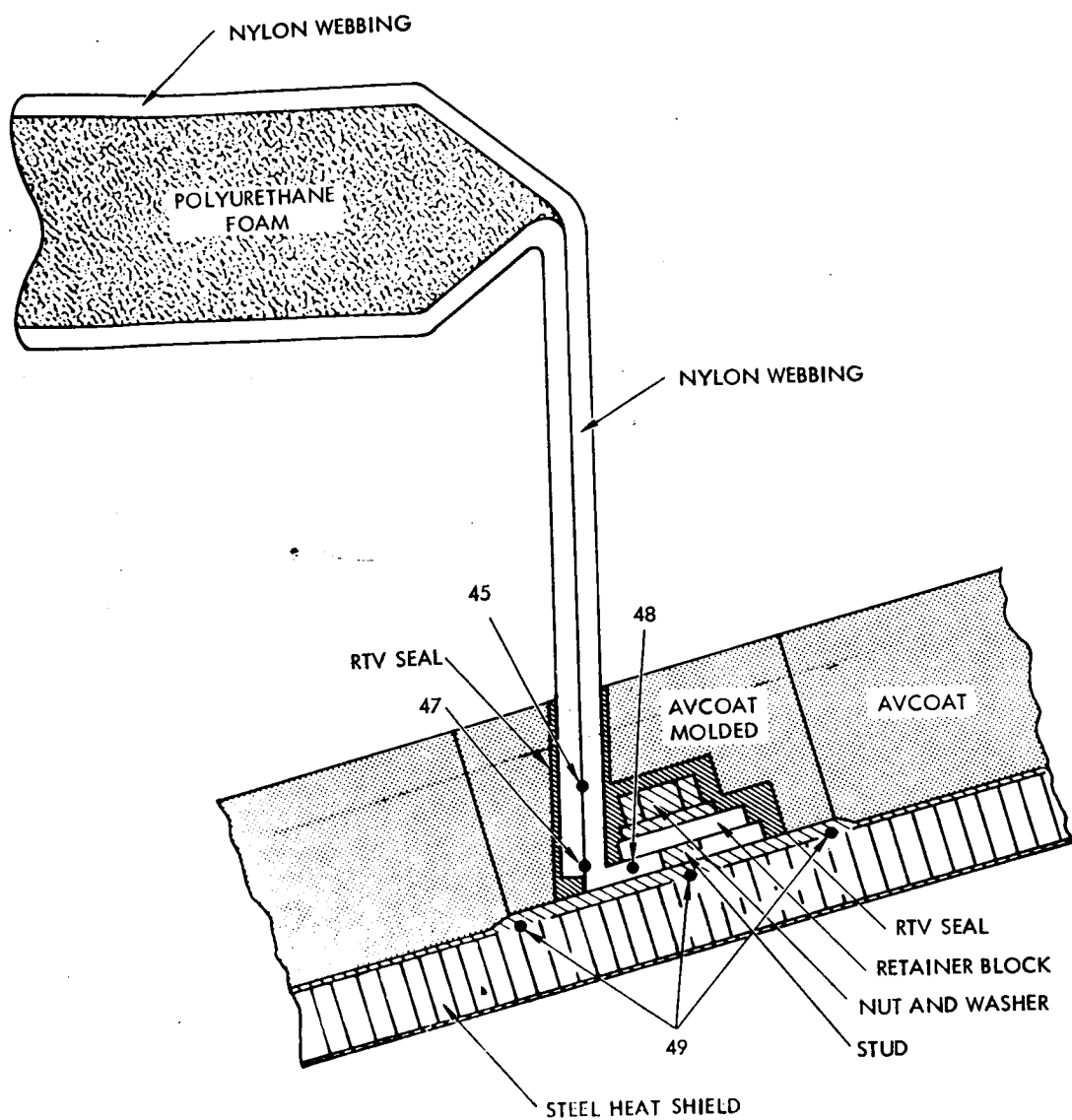


Figure 7. Forward Crew Hatch Flexible Handle

APPENDIX B

APOLLO 16 TRANSEARTH EVA COMMENTS

KEN MATTINGLY QUESTIONS AND COMMENTS

1. Describe the Apollo 16 Command Module EVA

Two film canisters (about 27-lb and 85-lb) were retrieved, a microbial experiment was assembled and latched into place, a general inspection was performed, and the command module hatch was opened and closed in a confined space.

The canister translation mode was to grip the handle with his glove, and then grasp both the handle and the handrail during locomotion. This resulted in some difficulty with the larger canister.

During installation of the microbial experiment he was body anchored and could not restrain his feet. This resulted in difficulty.

During inspection tasks Ken stabilized himself with either one or both hands, without foot restraints.

The foot restraints used on the EVA provided the capability to push-pull reasonably well, but allowed the feet to pop-out when leaning to the side and pulling. (Frank DeVos injected that Skylab restraints won't pop-out).

2. Problems During EVA

Glove friction in the wrist area was the major problem, leading to poor wrist endurance. The left glove was not as well broken-in as the other, and both less than the training gloves. The result was that the left wrist "wiped-out" in about 10 minutes. Hooking the tether was a problem because of wrist fatigue.

The basis of the problem is that the zero-g tasks Ken performed required a fine force application using the fingers and wrists, and these small forces had to be applied on top of a relatively large breakout force.

3. Simulation

Ken feels that the KC-135 is the only satisfactory means of simulating zero-g tasks. The water immersion facility is the only satisfactory means of continuous simulation and establishing of timelines. Because of viscosity effects in water tanks, the fidelity of task simulation is inferior.

4. Umbilicals

During the EVA Ken had no problems, whatsoever, with the umbilical, although he was worried because it was out of sight, and concerned that it would snag the RCS. The second crewman, standing in the open hatch, kept the slop out of the umbilical, and Ken felt that the umbilical management would have been very difficult without the second man.

In general, Ken feels that there is some length at which an umbilical would become too dangerous. He is concerned with ensnarling it with the shuttle manipulator. Wadding-up in a close space would be another problem. He stated the need for a take-up mechanism/retraction device. He mentioned that umbilicals impose torques on the crewman. He did not have a universal preferred tether or umbilical attach-point location, feeling it will depend on suit design and mode of operation.

5. Translation, Restraint and Work Performance

Ken recommended slow translation rates to minimize acceleration and deceleration forces, even though rapid translation is possible. He performed exactly as they had practiced. He turned loose only a short time during translation, and feels "soaring" is an acceptable mode only when inside. He would operate IVA in the cargo bay without tethers. His philosophy is to operate in the mode for maximum range of safety.

Transfer of cargo up to 100 lbs was easy, but Ken did not have a feeling for the limit. Hand carrying of items is acceptable.

Handrails and holds are adequate for position keeping if no large torque production is required. He had no comment on the use of leg rails. Ken feels that the ability to apply a force/torque in zero-g depends on how well the crewman is anchored, but thinks man should not be used as a power device.

The Apollo 16 restraint provisions were judged to be adequate for the job, but the Dutch Shoes were too specific for universal application. His general comment was that tasks were easy if good restraint was provided, but if the hands had to be used both to provide restraint and to apply leverage the task performance was inefficient. He was able to utilize existing structure to restrain himself with his legs. Ken likes hand holds plastered everywhere. He thinks velcro restraints are of little value.

Ken commented that the secret of doing tasks in zero-g is to work slow and methodically.

He thinks retractable tethers are fine, but unreliable.

6. Maneuvering Units

Ken was receptive to maneuvering units for the shuttle. He feels they should be tethered unless redundant systems are used. There is a problem in going after a malfunctioned unit because you lose visual contact rapidly as a result of the poor contrast.

To prevent disorientation, Ken feels a pictorial display may be required to provide artificial orientation.

7. Manipulator Interfaces

Ken believes an EVA crewman will be more cost effective than a manipulator; he sees possible replacement of EVA with the manipulator on later flights. He likes

the cherry-picker concept, and suggested potential replacement of free-flyers with the cherry picker. He favors foot restraints on the cherry picker, and, in any case, the restraint should be fail-safe to permit egress. He prefers control by the EVA man on the cherry picker.

In working with the manipulator, he thinks man should not be used as a power device, but could act as a vernier.

He looks at designs from the viewpoint that they will break - how can the man save himself?

8. Visibility and Lighting

Visibility during the Apollo 16 EVA was excellent, reflections were no problem, and the white paint and suit were helpful. Both visors were down all the way, and the visor shades were partially extended. He suggested that the Apollo LEVA would be a good baseline for the Shuttle.

Ken would prefer IVA work in cargo bay, which would permit better lighting than with the doors open.

Use of the optical telescope with long eyepieces and the pressure helmet worked great.

EVA out of the line of sight of another crewman was done on Gemini and will be done on Skylab. Ken says this is not comfortable, and should be considered on an individual - case basis.

9. EVA Duration and Feeding

Ken recited that Apollo EVA's to 7-1/2 hours gave no problems. Zero-g EVA's may need to be less because of using different muscles which tire easily (especially wrist muscles).

He recommends that EVA feeding be avoided if possible, although it may be needed if 7-8 hour EVA's are performed. He was not thirsty on his EVA. Skylab will use Apollo drinking bags. Drink bags should be avoided in zero-g if possible because of the potential problem of free liquid in the suit.

10. One-Man EVA's and EVA Hazards

Gemini and Apollo transearth EVA's were one-man from the viewpoint of safety, and would have been no different if the hatch had been closed.

Ken thinks EVA is more hazardous than inside the spacecraft, and thus would rather not send two men out if one can do the job. He feels EVA is more hazardous because of the smaller pressure vessel giving less margin when a leak occurs, because soft goods are hard to inspect, and because more moving parts are involved.

Ken believes that a decision to permit one-man EVA's without the "buddy system" on the Shuttle will be a major driver on the EVA system design.

11. Configuration

Relative to the distribution of components between a backpack and a chestpack, Ken considers both are needed. He mentioned that a chestpack is better for visibility and access to controls, but likes a backpack in order to move bulk out of the work area - he prefers to keep the chest area as clear as possible.

He does not think tack-on junk bags are good. He suggested that leg-mounting components might be cumbersome, but remarked that the Russians do it. He does not think a heads-up display is worth it.

12. Connectors

Relative to single vs composite connectors, Ken prefers as few connectors as possible.

Although he would prefer not to, he would make a vacuum disconnect if it were non-critical, but would avoid penetration of the pressure vessel. The design would have to permit easy accomplishment of the connection/disconnection. Concepts would be needed on how to verify connections. Apollo had poor human factors considerations on making connections.

13. Donning and Checkout

Ken wondered about the advisability of making the EVA system totally self-donning, and remarked that using two crewmen would permit a cheaper design.

Relative to reducing donning and checkout time, Ken noted that the Apollo equipment really wasn't designed for checkout. He remarked that he would not want to give up functional checks. He would want automatic switch-over of a system only if it were time-critical. He likes safety tones.

14. Emergency Systems

The OPS used on the Apollo 16 transearth had a nominal 45 minute capability. Ken considered it to be a 1-hour device and was prepared to do the whole EVA on the OPS.

Ken emphasized the importance of a check list and slow and methodical conduct of tasks in an emergency. He recalled 1-2 minute translation time from the SIM to the CM, 2-3 minutes to close the hatch.

His thoughts on an emergency system are to keep it simple - thus a preference for the simple OPS plus BSLSS on the Apollo vs the SLSS (small PLSS). He had no other basic preference for open loop vs closed loop systems.

He would prefer not to fly the Shuttle without an IV suit, especially on early flights.

15. Crewman Comfort and Control

The open loop vent gas cooling was completely adequate on the Apollo 16 EVA. Ken never felt dehydrated. He commented that cooling on the umbilical was the same in flight as in the altitude chamber. He also mentioned that during the donning

phase, prior to dumping the cabin pressure, cooling was insufficient.

On lunar missions, using the PLSS with its liquid loop for cooling, the usual procedure was to set the diverter valve and leave it. In reference to the possibility of replacing the manual water temperature control with an automatic one, Ken noted the cost savings with manual systems, and stated his preference for an infinite range of selection on a manual system.

He mentioned that the PLSS was comfortable.

16. Waste Management

Ken feels an EVA fecal containment system should be used, although no one likes it. If things get bad, it would really be needed as the fecal matter would clog the life support system. They had diarrhea during the Apollo 16 flight.

17. Disorientation

This is not a problem unless a point of reference is not available, then it can be. Ken said they tried a dark cockpit experiment and determined that tasks could be done as long as he held on to provide a point of reference.

18. Pressure Suit and Prebreathing

The A7L suit was completely satisfactory for his EVA, but he emphasized that the tasks were designed to accept suit capabilities. The bulkiness of the gloves and the high finger and wrist forces were the problem areas. For the tasks involved, the shoulder and leg mobility, glove tactility, and lack of waist mobility were acceptable. He mentioned that the astronauts purposely selected too-short gloves for maximum tactility, leading to sore fingers. He feels that maximum mobility is desired, though, and thinks he could have used waist mobility to advantage. The range of adjustments was adequate on Apollo suits, although the shortness of the arms was limited.

Ken had no opinion on 3-finger gloves, but thought the idea was worth trying. He likes lights on fingernails, but said no one to date had requested they be installed.

He felt that pockets should be defined once requirements are better established, and observed that they were not used for the intended purposes on Apollo. He would prefer a tool box to hanging things off the suit in zero-g.

Ken suggested that it may be more cost effective to have a single suit to accommodate both EVA and IV passenger needs, although he suggested consideration of a bag for passengers.

Ken would prefer prebreathing if the lower pressure level gives better EVA performance. He thinks the no-prebreathing argument for contingency situations is a poor one - just wear the suit all the time. The suit could be made to take 8 psi during the prebreathing period (with inhibited mobility) and then bled down

to 4-5 psi for EVA/IVA activities. (The reduced mobility at 8 psi should be adequate for emergency IV).

19. Psychological

Ken does not believe psychological effects are of significance - he does think training is important. It is also necessary to be sure you can take the next step. He mentioned that there is an effect of having things around you, in that he felt way out on his EVA. He did not see that this should have any influence on choosing a maneuvering backpack vs a maneuvering work platform.